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TECHNICAL REPORT

NO. 12347

U.S. ARMY TARADCOM

RECORDED SIMULATION CONTROL SCHEME

USER'S MANUAL

VOLUME II

January 1978

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by FOSTER-MILLER ASSOCIATES, INC.

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R.B. Fish

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U.S. ARMY TANK-AUTOMOTIVE
RESEARCH AND DEVELOPMENT COMMAND
Warren, Michigan 48090

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for

U. S. Army Tank-Automotive Research and Development Command
Warren, Michigan

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1. INTRODUCTION

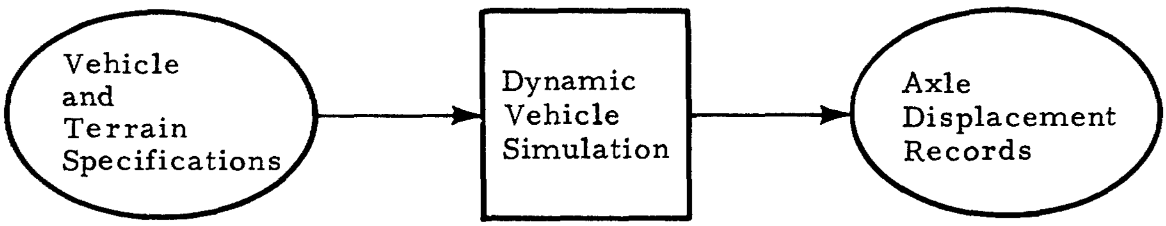
Recorded Simulation Control Scheme is a method of generating input signals for vehicle shake tests performed in laboratory. In this scheme a computer program is used to simulate operation of the vehicle being tested over a terrain of interest. The simulation results create axle displacement records which are stored in memory of a control system. At the time of shake test, these records are played back to generate axle displacement signals. Thus the scheme involves two distinct steps of operation; (a) creating axle displacement records, and (b) generating shaker input signal, as shown in Figure 1.

There are several ways of implementing the recorded simulation control scheme, with the same basic approach of recording the computer generated axle displacement signals and playing them back at the time of shake test. The implementation scheme selected in this effort is shown in Figure 2. As shown in the figure, the axle motion records are generated by dynamic vehicle simulation computer program. Data necessary to execute the program include:

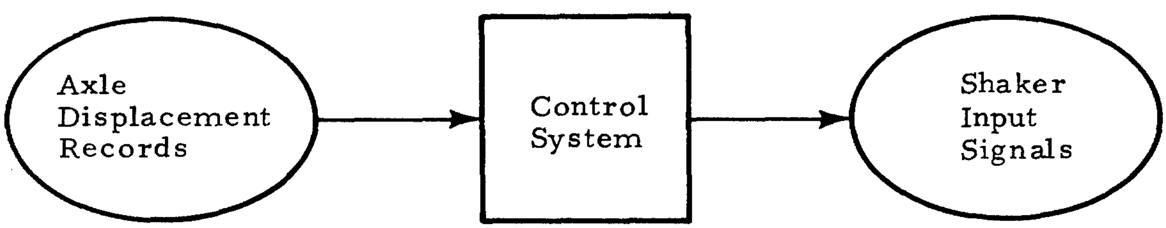
a. Vehicle data (mass, CG location, wheel base, etc.)
b. Operation data (terrain profile and speed of operation).

The axle displacement records generated by the simulation are stored on paper tapes and transferred to magnetic disc of a digital controller through adequate software. The data stored on the magnetic disc are retrieved at the time of running the shake test, and the digital signals are converted to analog signals using a bank of digital to analog signal converters. The analog signals are then fed to the shaker through appropriate filters and amplifiers.

The records stored on the discs typically last less than a minute in real-time; therefore, the same records are repeated until the testing is completed. Also, the simulation program is executed each time the vehicle test parameters (terrain profile, speed, load) are changed and the axle displacement records on the discs are updated to show the changes.



Step 1: Creating Axle Displacement Records



Step 2: Generating Shaker Input Signals

Figure 1. Recorded Simulation Control Scheme

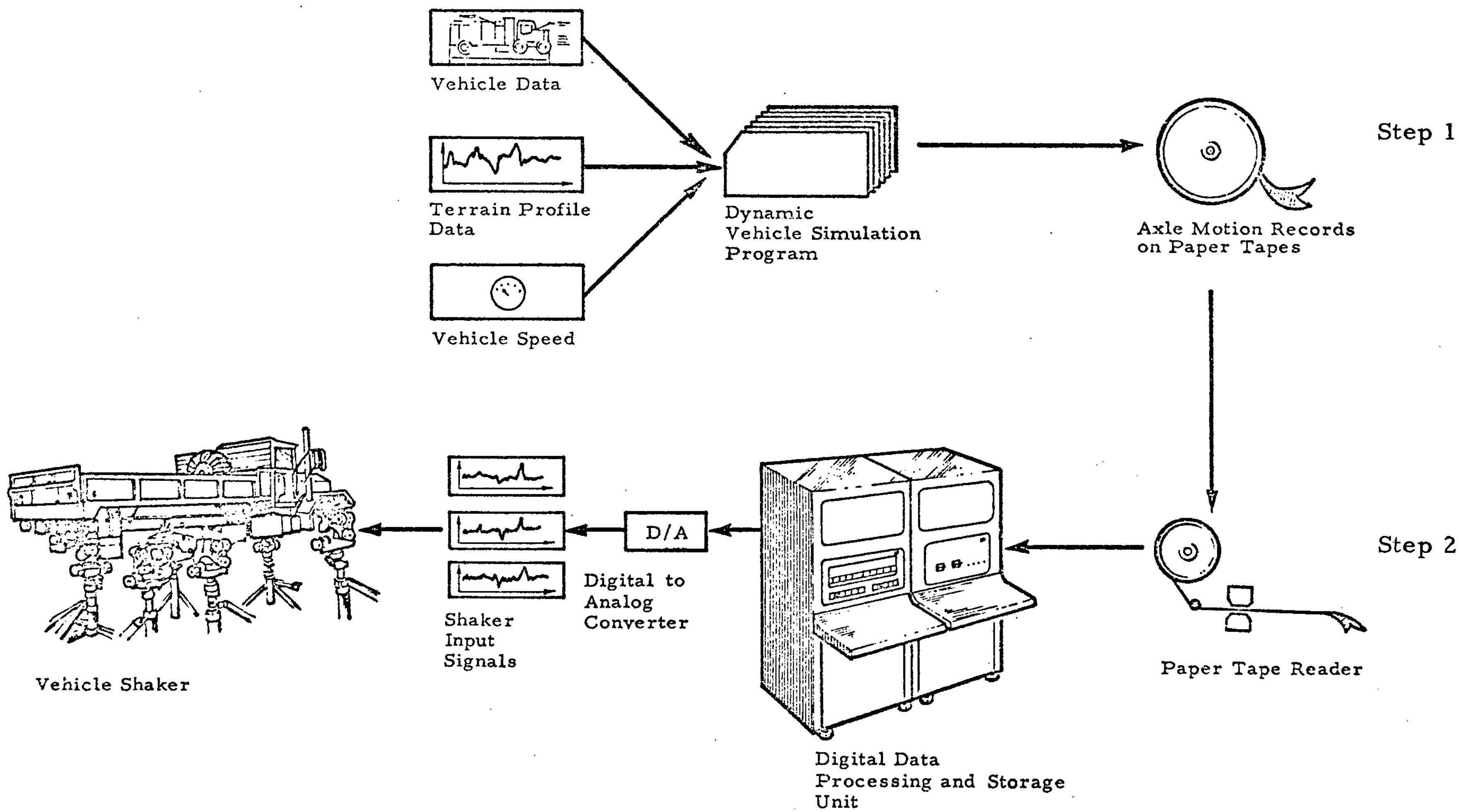


Figure 2. Implementation of Recorded Simulation Control Scheme

This manual describes both steps of the recorded simulation control scheme. Section 2 deals with creating axle displacement records from the specifications of vehicle and terrain, whereas Section 3 discusses the control system which converts the records to shaker input signals. Instructions on how to execute both the steps are given along with appropriate illustrative examples.

2. STEP 1: AXLE DISPLACEMENT RECORDS FROM VEHICLE AND TERRAIN SPECIFICATIONS

This chapter deals with the first of two steps involved in implementing the recorded simulation control scheme. The details of the first step are illustrated by Figure 3. As shown in the figure, the input to the first step is in form of specifications for the vehicle and operation, where the vehicle specifications include parameters such as dimensions of the vehicle, spring constants of the suspensions, and weights of the components. The operation specifications, on the other hand, include details of the terrain profile and speed of the vehicle. If the profile of the terrain is not known, its roughness parameter is sufficient to generate a random profile using an associated program, GRND, described in Appendix A.3.

The vehicle data and terrain profile are fed to the dynamic vehicle simulation program to obtain simulation results. The output of the program is in many forms, as shown in the figure. The printout summarizes the input parameters and the dynamic simulation results. The simulation results are in form of values of the key vehicle variables listed as a function of time. The program also can generate plots of the variables, either versus time or versus horizontal vehicle displacement. The axle displacement results generated by the simulation program are punched on cards and they can subsequently be transferred to paper tapes which store data in standard ASCII format. As an option available to the user, the output of some of the variables can be stored on a tape for future statistical processing by an associated program, SPEC, described in Appendix A.3.

The rest of this section deals with the dynamic vehicle simulation program.

The operation of the program is described in Section 2.1. Section 2.2 deals with instructions on how to use the program and Section 2.3 illustrates the use with an example. Details of the subroutines, program nomenclature, associated programs (GRND and SPEC) and listing of the program are in Appendix A.

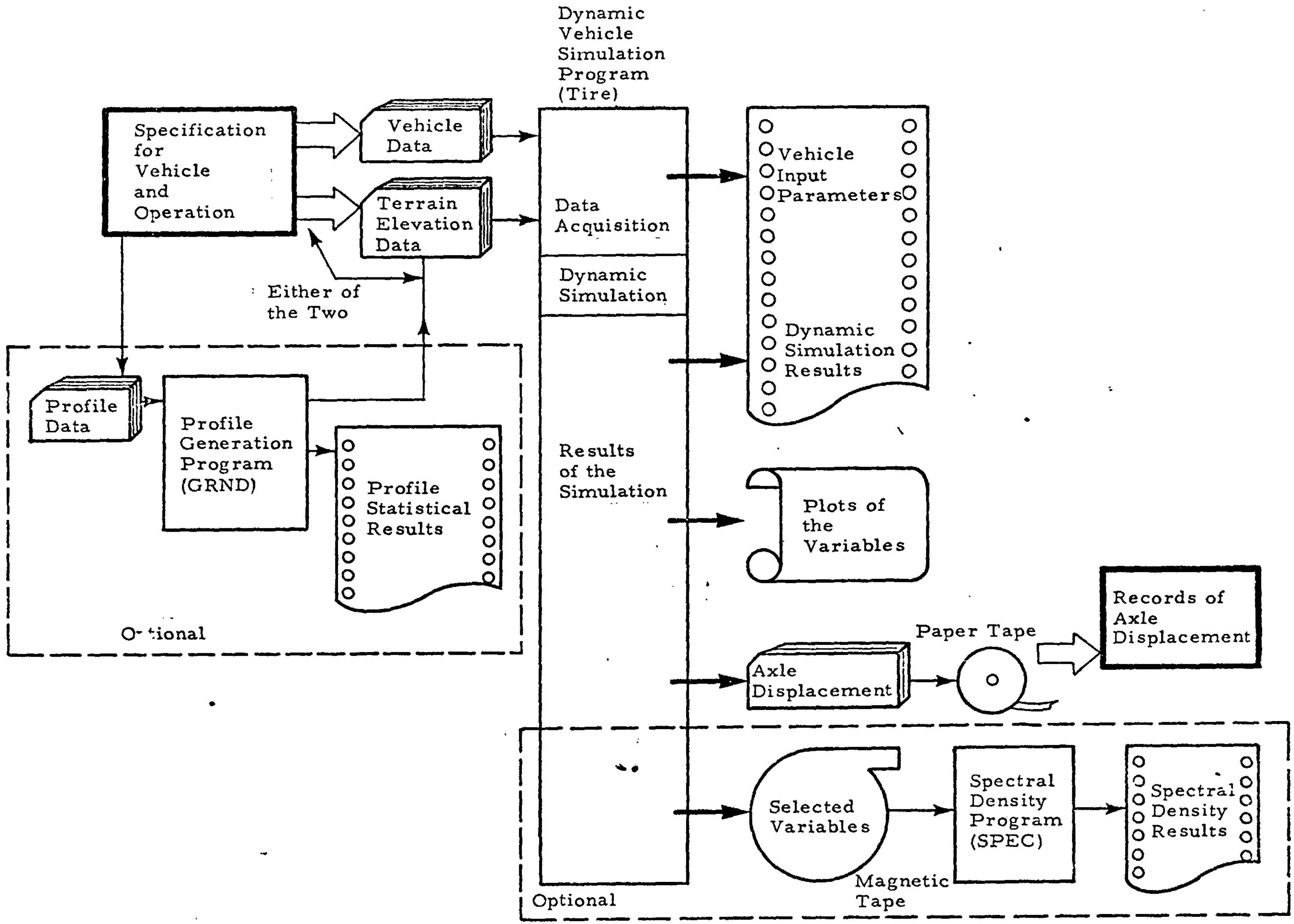


Figure 3. Details of the First Step of the Recorded Simulation Control Scheme

2.1 Dynamic Vehicle Simulation Program

The terrain-tire-vehicle model developed in reference 1 is incorporated in a computer program with specifications summarized in Table 1. The program simulates operation of a vehicle, shown schematically in Figure 4, over a given terrain at a given speed. In the diagram describing the vehicle model, the tire models are not shown because the program offers a choice of four tire models. These models are briefly described in Table 2. For details of the vehicle and the tire models, the user is advised to read reference 1.

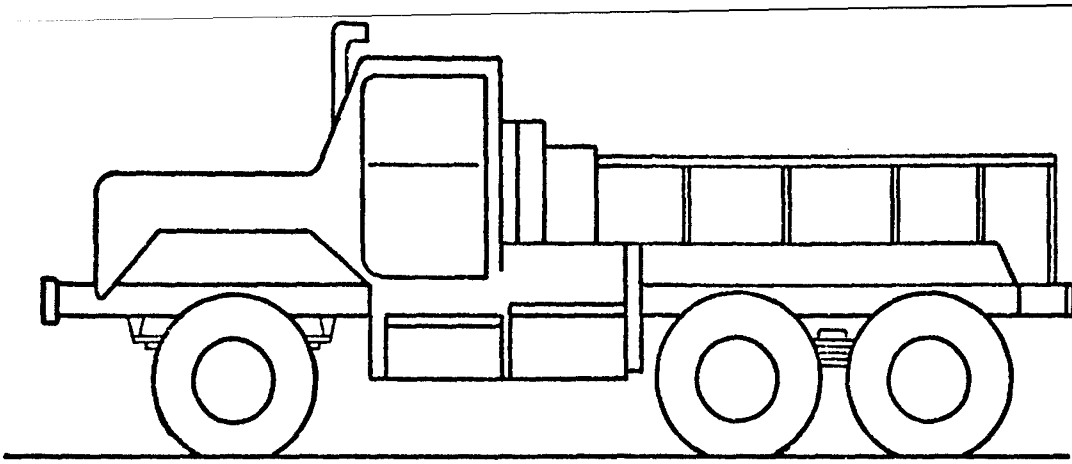
Table 1. Specifications of the Computer Program

Language:	FORTRAN IV
Compiler:	Run (Control Data)
Core Used:	70K Octal
Additional Requirements:	CALCOMP Subroutines Plotter Card Punch Paper Tape Punch*

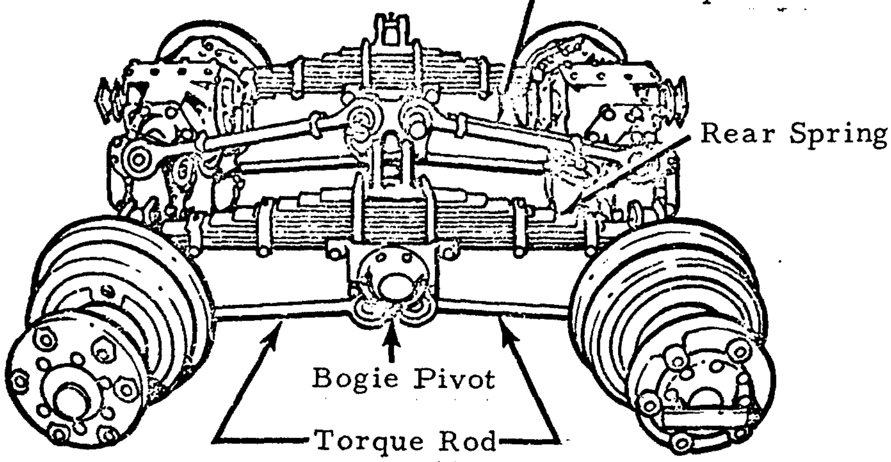
For a typical vehicle simulation over 500 feet of terrain:

	Using Any of The First Three Tire Models	Using Adaptive Footprint Tire Model
Typical CPU time on CDC 6400	100 sec	1762 sec
Typical cost (government rate)	$18	$58

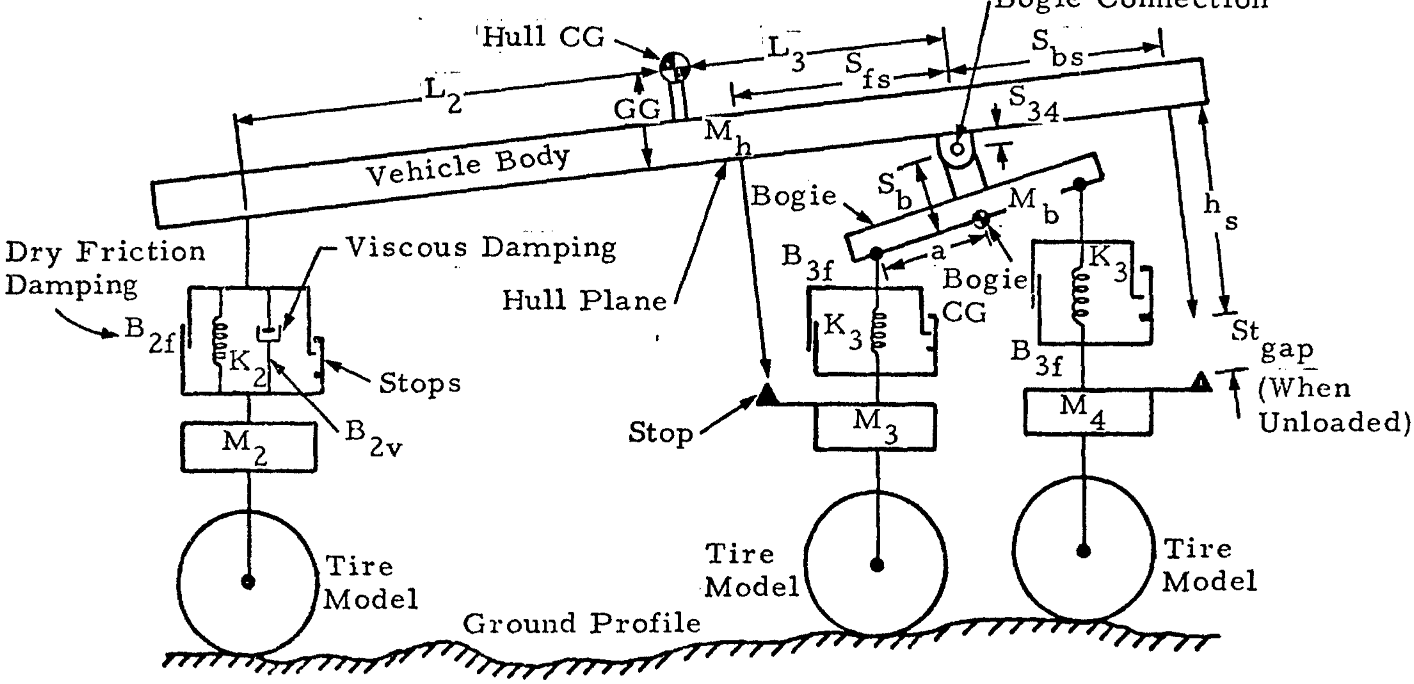
*Required if the control system needs the axle displacement records on paper tapes.



(a) M-809 Truck



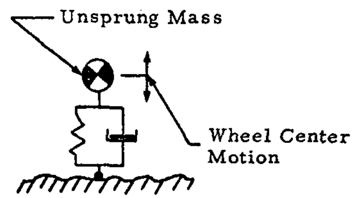
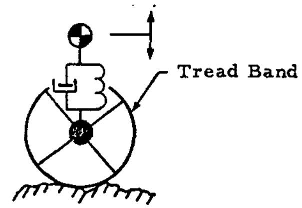
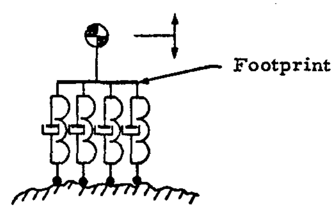
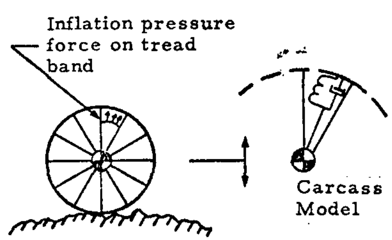
(b) M-809 Rear Suspension



(c) The Model of the Vehicle

Figure 4. Formulation of the Vehicle Model

Table 2. Summary of Basic Tire Models

Name	Schematic	Characteristics
1. Point Contact Tire Model		(a) Effects of inflation pressure and carcass stiffness represented by single spring-dashpot combination. (b) Effects of finite contact area neglected; i.e., no enveloping capability. (c) Effects of finite tire radius neglected; i.e., terrain contact point vertically below wheel center.
2. Rigid Tread Band Tire Model		(a) Rolling Circular Tread Band. (b) Effects of inflation pressure and carcass stiffness represented by an equivalent radial spring-dashpot combination. (c) Ability to filter small wavelength irregularities due to geometric constraints. (d) Terrain contact point shifted fore or aft of wheel center.
3. Fixed Footprint Tire Model		(a) Contact area independent of tire deflection. (b) Effects of inflation pressure and carcass stiffness represented in terms of linearly distributed stiffness and damping. (c) Ability to envelop small irregularities.
4. Adaptive Footprint Tire Model		(a) Contact area changes with tire deflection and conforms with terrain surface. (b) Effects of carcass stiffness represented in terms of angularly distributed stiffness and damping. (c) Effects of inflation pressure represented by an increase in ground contact pressure independent of tire deflection. (d) Capability to filter and envelop small irregularities.

The computer program incorporates the terrain-tire-vehicle model to simulate operation of the vehicle through the following five steps:

a. Vehicle parameter input
b. Profile data input
c. Initial condition calculation
d. Dynamic simulation
e. Plotting variables.

These steps are executed by the program through a number of subroutines. The usage of subroutines, each of which performs a specific function, makes the program modular in structure so that it can be modified just by changing the relevant subroutines and keeping the rest of the program untouched. The manner in which the main program interacts with the subroutines is shown in Figure 5. How this interaction performs the above five steps is described in the following:

a. <u>Vehicle Parameter Input</u>

Execution of the program begins by calling subroutine PROGIO which reads the input data for the vehicle and the tire models through three subroutines, IOLAB, IOLABD and IOLAB2. The data is in form of data cards with an alphanumeric description of the parameter, its value and the unit. This description for each data card is printed as soon as it is read. The parameters which are not in consistent units are then converted in the main program just after calling PROGIO.

b. <u>Profile Data Input</u>

Profile data consist of elevations of a random profile, with an rms value of 1 foot, generated by one of the associated programs, GRND, which is described in Appendix A. This profile data are read by subroutine PROFILE. Because the program may simulate vehicle operation on an endless profile, all the profile data are not read at once. Initially only as much profile is read as the program dimensions can absorb. Then the simulation

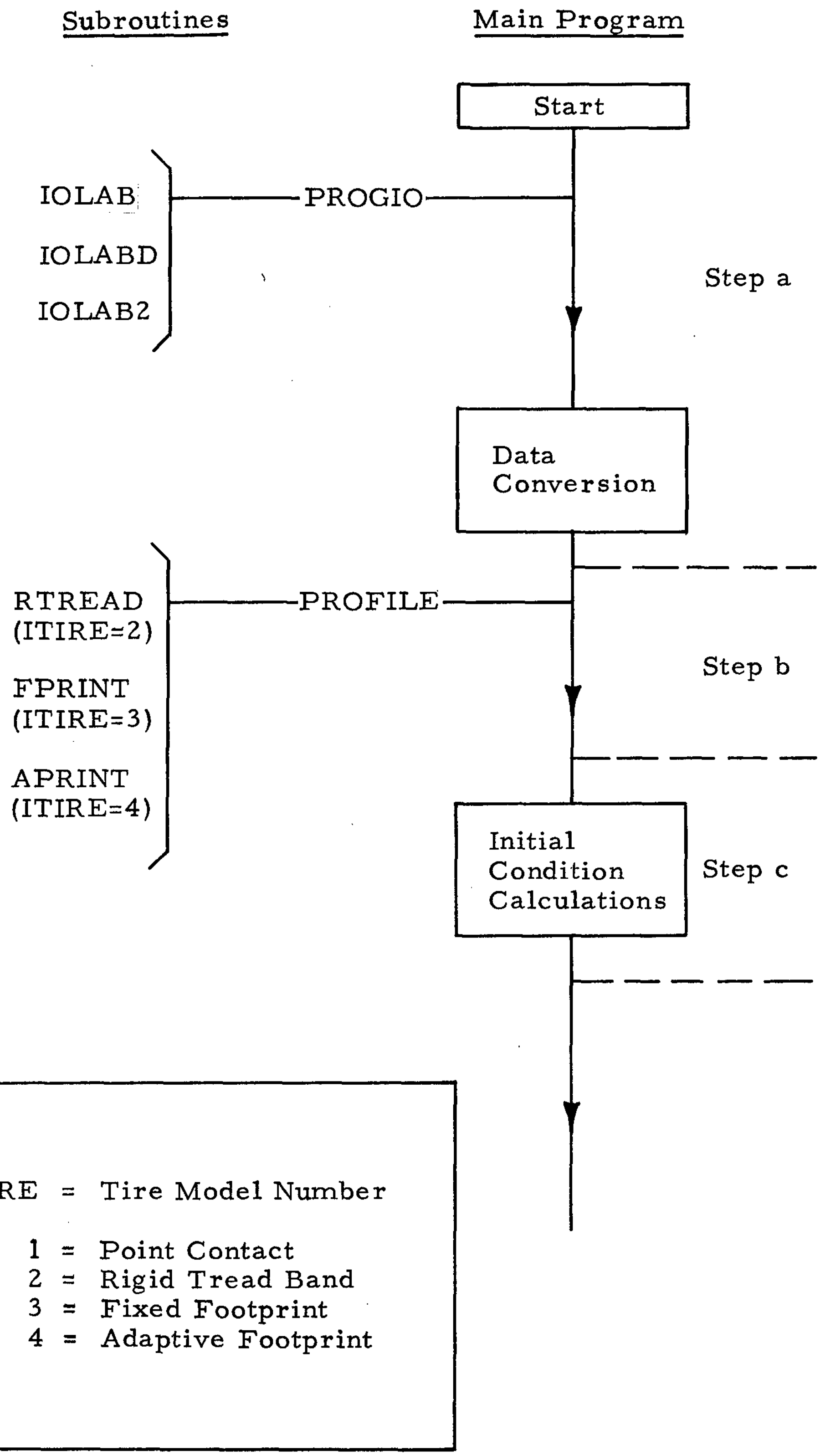


Figure 5. Main Program - Subroutine Interaction

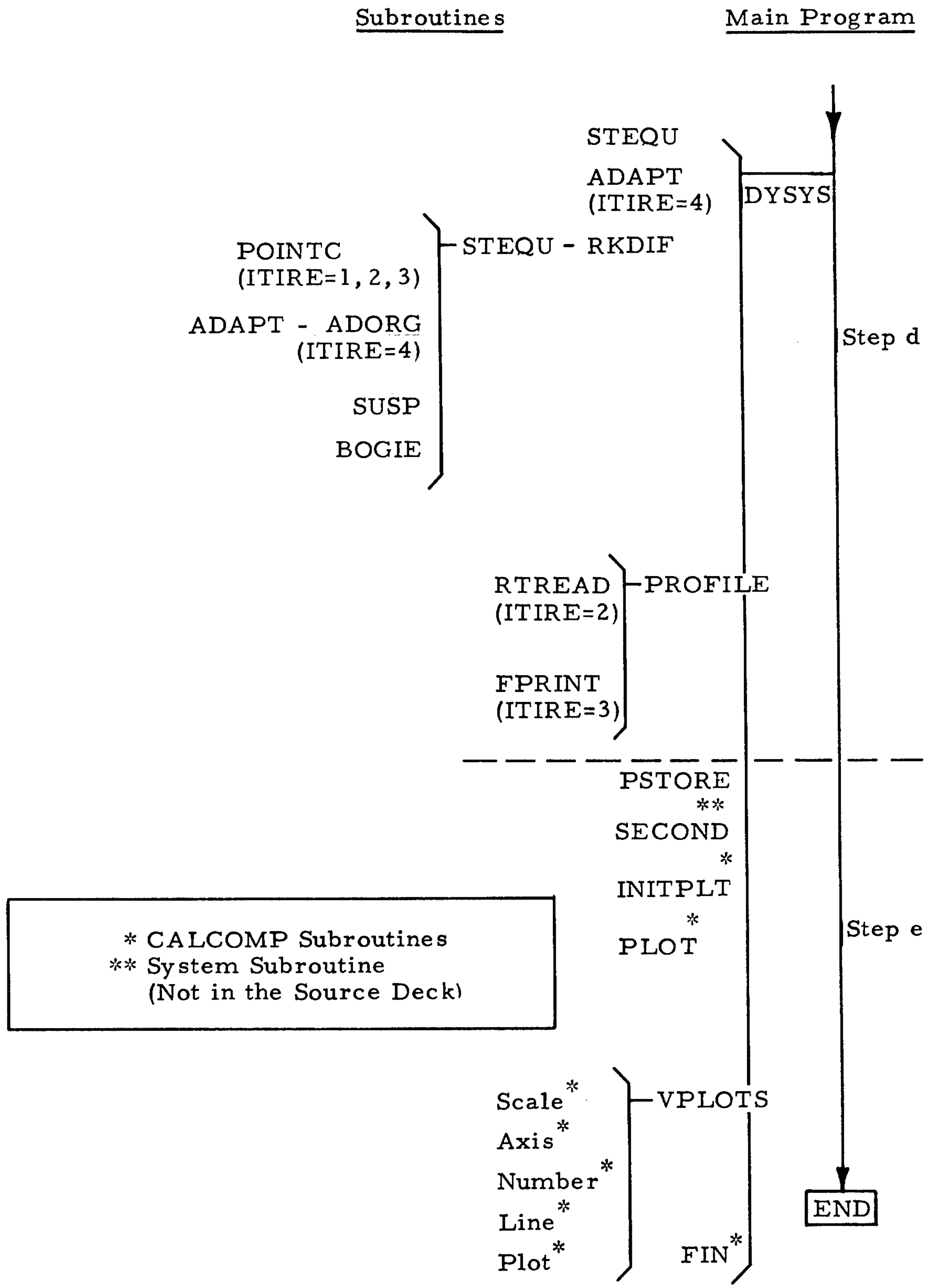


Figure 5. Main Program - Subroutine Interaction Continued

is carried out over that part of the profile. At the end of that profile part, another profile length is read in by PROFILE, and the process is repeated.

The profile thus read in is filtered by subroutine RTREAD if the rigid tread band tire model is being used and by subroutine FPRINT if the fixed footprint model is being used. The profile is then converted to a profile with the user specified rms value (the input profile has an rms value of 1 foot).

c. Initial Condition Calculations

From the data of the terrain on which the vehicle initially rests, the initial conditions of all the state variables are calculated in the main program.

d. Dynamic Simulation

Integration of the state equations to determine time histories of the state variables is coordinated by subroutine DYSYS. The subroutine calls subroutine STEQU in the beginning to initialize values of the state variable derivatives. Subroutine ADAPT is called next, if the adaptive tire model is being used, to determine the initial elevation of the tire center. After these initial calls, subroutine DYSYS executes the integration process by calling subroutine RKDIF at each time steps. Subroutine RKDIF incorporates a fourth order Runge-Kutta algorithm to numerically integrate the state equations. Through integration it updates the values of the state variables (displacements, velocities of the vehicle component) at each time step.

The state equations are programmed in subroutine STEQU, which is called four times at each time step by subroutine RKDIF. These state equations are differential equations describing the heave-pitch motions of the vehicle and its components. In order to determine updated values of the derivatives, subroutine STEQU calls subroutine POINTC, if any of the first three tire models (point contact, rigid tread band or fixed footprint) are being used. In case of the adaptive footprint tire model, however, subroutine ADORG (and through ADORG, subroutine ADAPT) is called instead of

POINTC. These subroutines calculate the forces exerted by the tires. Forces exerted by the suspension are determined by calling subroutine SUSP, whereas those exerted by the bogie are determined from subroutine BOGIE. From updated values of forces thus obtained, the values of derivatives are calculated by subroutine STEQU, from which, in turn, the updated values of the state variables are calculated by subroutine RKDIF.

Subroutine DYSYS generates outputs from the results of numerical integration in the following manner

(1) The values of the key vehicle variables are printed after MM (user selected) time steps.

(2) The values of time: and front, middle and rear axle displacements: are punched at each time step. The punched records can be converted to those on paper tapes according to the equipment availability at the user's installation.

(3) If plotting of certain variables is desired, subroutine PSTORE is called to store the variables to be plotted. The plots are then produced by subroutine VPLOTS.

(4) If statistical processing option is to be exercised, additional cards are required by subroutine DYSYS (as described in Appendix A.3) for storing the variables on magnetic tape.

Numerical integration is halted when additional profile data is to be read. Subroutine PROFILE is called and with the new profile data the the integration is resumed. The process is repeated until the end of the profile is reached. The execution is then moved to the next step. During the simulation, subroutine SECOND keeps track of the execution time.

e. Plotting Variables

If the user requires some of the variables to be plotted, CALCOMP subroutines INITPLT and PLOT are called to initialize the plotter. Subroutine VPLOTS is then called to create 6 by 5 inch plots of the variables versus time (or displacement as requested by the user). The plots are created using CALCOMP subroutines SCALE, AXIS, NUMBER, LINE and PLOT, which are called by subroutine VPLOTS. Plotting is termined by subroutine DYSYS through CALCOMP subroutine FIN.

After producing the plots, the program is terminated.

2.2 User Instructions

2.2.1 Program Input

The program obtains input through data cards. There are two main categories in which the data cards can be divided:

(1) Vehicle-tire parameters
(2) Terrain data.

The vehicle-tire parameters category includes masses of the vehicle components, stiffness of the suspensions, tire characteristics, etc. The terrain data is in form of ground elevation readings at a fixed horizontal distance. There is no limit to the length of the profile over which the simulation can be carried out. Also, if profile elevation data are not available, associated program GRND (described in Appendix A.3) can be executed to generate such data.

In the following pages the data cards necessary to execute the program are listed. The numerical values in these data cards are to be placed within the 'F', 'I' or 'E' format. The 'A' fields are used to provide parameter name and units, and other descriptive legends for user convenience.

DATA CARDS

General Description Data

Card No.	Contents	Format
1-6	Header cards (the user can print a heading using these cards)	80Al
7	Vehicle type	80Al
8	Tire type	80Al
9	Terrain No.	80Al
10	Tire model no., ITIRE ITIRE = 1 Point contact model = 2 Rigid tread band model = 3 Fixed footprint model = 4 Adaptive footprint model	40Al, I5
11	Vehicle speed, V (mph)	30Al, F10·4, 10Al
12	Profile rms, y_{rms} (in.) (see Note 1)	30Al, F10·4, 10Al

Vehicle-Tire Parameters (See Figure 4)

Vehicle Frame Parameters

Card No.	Contents	Format
13	Header card	80Al
14	Mass of hull, M_h (slugs)	30Al, F10·4, 10Al
15	Mass of bogie, M_b (slugs)	30Al, F10·4, 10Al
16	Front unsprung mass, each, M_2 (slugs)	30Al, F10·4, 10Al
17	Middle unsprung mass, each, M_3 (slugs)	30Al, F10·4, 10Al
18	Rear unsprung mass, each, M_4 (slugs)	30Al, F10·4, 10Al
19	Pitch inertia of hull, I_h (slug ft^2)	30Al, F10·4, 10Al
20	Pitch inertia of bogie, I_b (slug ft^2)	30Al, F10·4, 10Al

21	Horizontal distance between front suspension and hull CG, L_2 (ft)	30Al,F10·4,10Al
22	Horizontal distance between bogie connection and hull CG, L_3 (ft)	30Al,F10·4,10Al
23	Height of hull CG from hull plane, GG (ft)	30Al,F10·4,10Al
24	Vertical distance between bogie connection and hull plane, S_{34} (ft)	30Al,F10·4,10Al
25	Horizontal distance between bogie connection and front stop, S_{fs} (ft)	30Al,F10·4,10Al
26	Horizontal distance between bogie connection and rear stop, S_{bs} (ft)	30Al,F10·4,10Al
27	Vertical distance between bogie connection and bogie CG, S_b (ft)	30Al,F10·4,10Al
28	Half bogie length, a (ft)	30Al,F10·4,10Al
29	Stop size, h_s (ft)	30Al,F10·4,10Al
30	Stiffness factor, bogie - stop, K_{stop} (see Note 2)	30Al,F10·4,10Al
31	Stiffness factor, bogie - hull, H_{stop} (see Note 2)	30Al,F10·4,10Al
32	Unloaded clearance between frame stops and bogie, St_{gap} (ft)	30Al,F10·4,10Al
	<u>Suspension Parameters (See Note 3)</u>	
33-34	Header cards	80Al
	<u>Front Suspension</u>	
35	Stiffness, K_2 (lb/ft)	30Al,F10·4,10Al
36	Viscous damping constant (jounce), B_{2vj} (lb·sec/ft) (See Figure 6)	30Al,F10·4,10Al
37	Viscous damping constant (rebound), B_{2vr} (lb·sec/ft) (See Figure 6)	30Al,F10·4,10Al
38	Jounce travel, Jn_2 (ft)	30Al,F10·4,10Al
39	Rebound travel, Rb_2 (ft)	30Al,F10·4,10Al

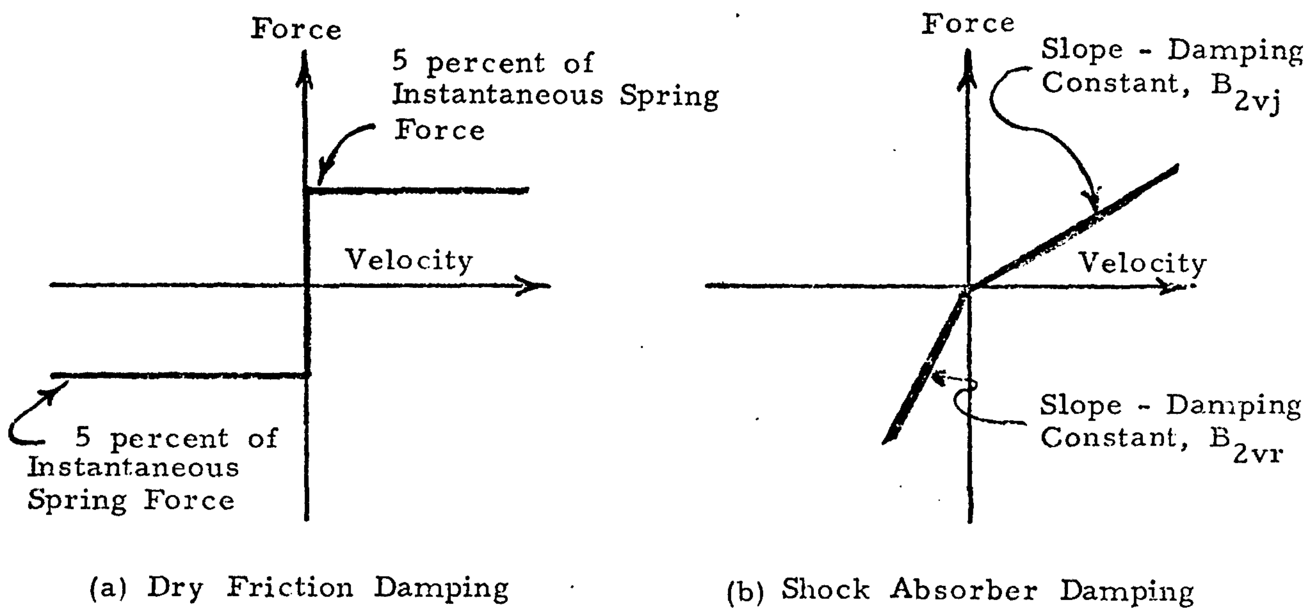


Figure 6. Damping Models

	Middle and Rear Suspensions	
40	Header card	80A1
41	Stiffness, K_3 (lb/ft)	30A1,F10·4,10A1
42	Jounce travel, Jn_3 (ft)	30A1,F10·4,10A1
43	Rebound travel, Rb_3 (ft)	30A1,F10·4,10A1
44	Stop stiffness factor, n (ft) (See Note 2)	30A1,F10·4,10A1
	Tire Parameters	
45	Header card	80A1
46	Tire stiffness, K (lb/ft) (See Note 4)	30A1,F10·4,10A1
47	Tire damping constant, b (lb·sec/ft) (See Note 5)	30A1,F10·4,10A1
48	Tire radius, r (ft)	30A1,F10·4,10A1
49	Tire footprint length, L (ft) (See Note 4)	30A1,F10·4,10A1
50	Tire distributed (cubic) stiffness, k'' (lb/in.^{3}) (See Note 6)	30A1,F10·4,10A1
51	Tire distributed (cubic) damping, b'' (lb·sec/ft^3) (See Note 6)	30A1,F10·4,10A1
52	Tire inflation pressure, p_i (psi)	30A1,F10·4,10A1
53	Tire deflection limit, T_ℓ (ft)	30A1,F10·4,10A1
54	Tire stiffness factor, T_{stif} (See Note 2)	30A1,F10.4,10A1

Simulation Data

	Printout Card	
55	MM, where the dynamic results are printed at every MM time steps	40A1,I5

Plot Card

56 (JPLT(K), K=1, 40), IXAX, PLSTR, PLSTP 41I1, 9X, 2F10·3

Column	Explanation
1-40	Punch 1 in the Kth column if Kth variable is to be plotted (See Table 3). Eight variables maximum.
41	IXAX=0, If X axis on plots is distance travelled (XREAR) IXAX=1, If X axis is time
51-60	Distance travelled at the first point of the plot (as measured by rear wheel center horizontal displacement)
61-70	Distance travelled at the last point of plot (as measured by rear wheel center horizontal displacement)

Terrain Data

57	(1) Fixed horizontal distance between the data points, dx (ft) (2) Total number of data points, JMAX	F10·2, I5
58 and onwards	Terrain elevation data, in ten columns, eight on each card (ft). TER(J), J=1, JMAX	8E10·3

Note 1: This assumes that the terrain profile used in the illustrative simulation has been generated by an associated program, program GRND described in Appendix A.3. This profile has an rms (root means square) elevation value of 1 foot. A profile with a different rms value, but with a similar spectral density can be obtained by simply multiplying the generated profile by the rms value supplied by the user through this data card. If, however, a terrain profile with correct rms value is already available to the user, either through experimental results or through some other terrain generating program, this data card

Table 3. List of Variables Available for Plotting

Variable Number	Variable	Program Symbol	Dimension
1	Hull pitch angle	THETA	degree
2	Hull pitch velocity	DTHETA	degree/sec
3	Bogie pitch angle	PHI	degree
4	Bogie pitch velocity	DPHI	degree/sec
5	Hull CG displacement	Y0	ft
6	Hull CG heave velocity	DY0	ft/sec
7	Front axle displacement	YW2	ft
8	Front axle heave velocity	DYW2	ft/sec
9	Middle axle displacement	YW3	ft
10	Middle axle heave velocity	DYW3	ft/sec
11	Rear axle displacement	YW4	ft
12	Rear axle heave velocity	DYW4	ft/sec
13	Front tire force (vertical) (expressed as fraction of the equilibrium force)	FV2/WTR2	Dimensionless
14	Middle tire force (vertical)	FV3/2WTR3	Dimensionless
15	Rear tire force (vertical)	FV4/2WTR4	Dimensionless
16	Front tire force (horizontal)	FH2/WTR2	Dimensionless
17	Middle tire force (horizontal)	FH3/2WTR3	Dimensionless
18	Rear tire force (horizontal)	FH4/2WTR4	Dimensionless
19	Front suspension force (vertical)	FY2	lb
20	Middle suspension force (vertical)	FSY3	lb
21	Rear suspension force (vertical)	FSY4	lb
22	Front ground elevation (effective)	Y2	ft
23	Middle ground elevation (effective)	Y3	ft
24	Rear ground elevation (effective)	Y4	ft
25	Bogie CG elevation	YB	ft
26	Hull CG acceleration	D2Y0	ft/sec^2
27	Front suspension displn.	DEL2	ft
28	Middle suspension displn.	DEL3	ft
29	Rear suspension displn.	DEL4	ft
30	Original terrain profile (as seen by the rear tires)	OTER(KPHS)	ft
31	Effective (filtered) profile (as seen by the rear tires)	TER(KPHS)	ft

should have a value of 12.0 inch, so that the terrain rms value is not readjusted in the program.

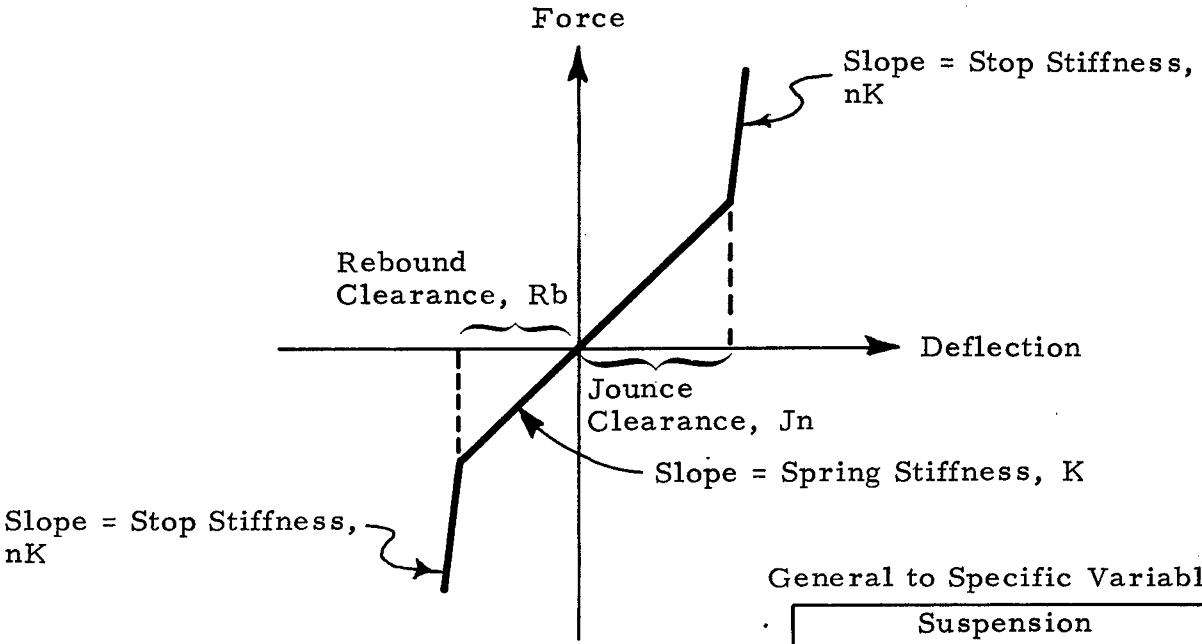
Note 2: Stiffness factor is defined as a factor by which the normal stiffness should be multiplied to simulate a hard contact. Thus, when the suspension exceeds its jounce or rebound limits, its stiffness gets effectively multiplied by a factor n, as shown in Figure 7. Similarly when the tire deflection exceeds the limit, T_ℓ, its stiffness gets multiplied by factor T_{stif} (see Figure 7 (cont)). For the frame stops, the situation is different, because unless the gap between the stop and the bogie becomes zero, there is no force acting on the bogie and hence the stiffness factor, when the contact does occur, has to be keyed to some other stiffness. This stiffness chosen is the suspension stiffness for the middle and the rear suspensions. Thus, the stiffness of the stop is $K_3\ K_{stop}$, as shown in Figure 7. In extreme case, when the bogie touches the hull, the effective stiffness is $K_3 \cdot H_{stop}$.

Note 3: One of the missing parameters in the suspensions data is dry friction coefficient, which is extremely difficult to model. Initial experiments at TARADCOM have indicated that a force value equal to 5 percent of the instantaneous spring force which opposes the velocity describes the dry friction approximately.

Note 4: Typical design curves supplied by the tire manufacturer are shown in Figure 8. From such a curve, knowing the equilibrium load, W, and inflation pressure, p_i (PRESS), equilibrium deflection, YST, can be determined. Inverse of the slope of the curve at point A will give the stiffness value k. The following equation determines footprint length, L.

$$L = 2r \sin\left(\cos^{-1}\left(\frac{r - YST}{r}\right)\right)$$

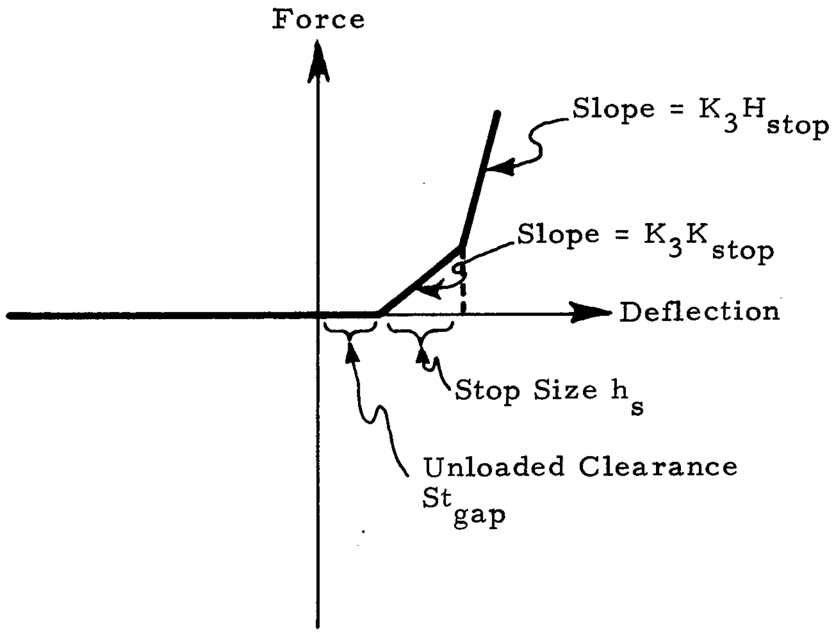
where r is radius of the tire. The user should refer to reference 2 for details on tire stiffness.



General to Specific Variables

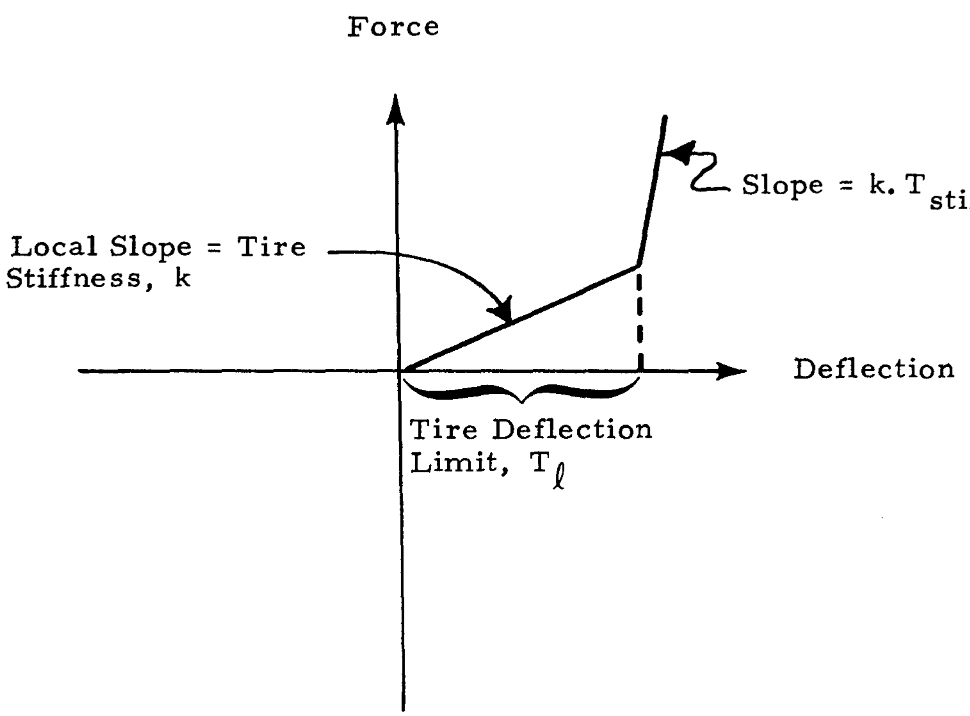
	Suspension		
	Front	Middle	Rear
K	K_2	K_3	K_3
Jn	Jn_2	Jn_3	Jn_3
Rb	Rb_2	Rb_3	Rb_3

(a) Suspension Springs



(b) Rear Wheel Frame Stops

Figure 7. Force Characteristics of Suspension Springs, Frame Stops and Tire



(c) Tire

Figure 7. Force Characteristics of Suspension Springs, Frame Stops and Tire (Continued)

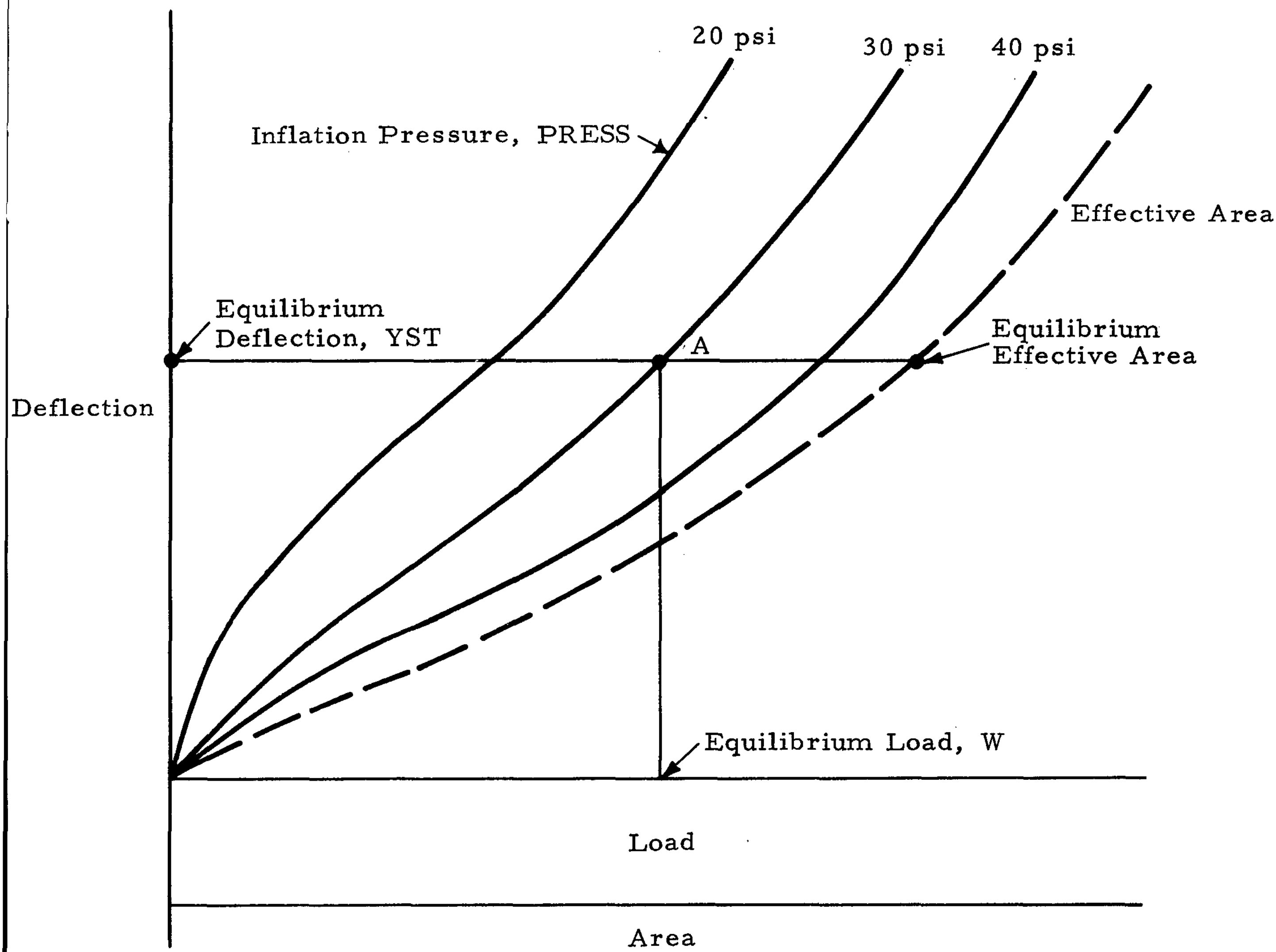


Figure 8. Typical Design Curves for Tire

Note 5: Data on tire damping are relatively scarce. Typical experimental results on tire damping have indicated the damping ratio, ξ, to be in a 0.03-0.08 range. For the illustrative simulations in this report a mean value of $\xi = 0.05$ has been assumed. From ξ, the damping constant b can be determined from the following relation

$$b = 2\sqrt{km}\ \xi$$

where m is the mass of the tire in slugs and k is the stiffness in lb/ft. More details on the tire damping are available in reference 2.

Note 6: The value of the distributed (cubic) stiffness of tire, which is used in the adaptive footprint model, k'', can be evaluated by considering deflection at the equilibrium condition:

$$k'' = \frac{w - p_i A}{B\left(r^2 \sin\theta_o - \frac{(YST-r)^2}{2} \ell n\left(\frac{1+\sin\theta_o}{1-\sin\theta_o}\right)\right)}$$

where
B = effective width of the tire = A/L
A = effective footprint area at equilibrium obtained from Figure
$\theta_o = \cos^{-1}\left(\frac{r - YST}{r}\right)$
w = equilibrium force on the tire.

The cubic damping coefficient, b'', is evaluated from the tire damping coefficient, b:

$$b'' = \frac{b}{2 B r \theta_o}$$

2.2.2 Program Output

The program generates outputs in three forms:

a. Printout

b. Plotter output

c. Punch output

The fourth form of output, i.e., magnetic tape for statistical processing of the stored variables, is optional and the user is referred to Appendix A.3 for more details.

2.2.2.1 Printout

a. The Input Parameters

All the vehicle parameters read from the data cards are listed with the appropriate units.

d. Dynamic Simulation Results

Values of the following variables after every MM (user supplied) time steps* are printed:

NO.	Serial Number	
TIME	Time elapsed from beginning of the simulation	(sec)
FV2	Vertical force from each of the front tires	(lb)
FV3	Vertical force from each pair of the middle tires	(lb)
FV4	The above for rear tires	(lb)
FH2	Horizontal force from each of the front tires	(lb)
FH3	Horizontal force from each pair of the middle tires	(lb)
FH4	The above for the rear tires	(lb)
YW2	Front axle displacement	(ft)
YW3	Middle axle displacement	(ft)
YW4	Rear axle displacement	(ft)

*The time steps are such that the vehicle advance by a distance dx at each step. See Data Card No. 57 for the value of dx.

Y0	Hull CG displacement	(ft)
THETA	Hull pitch angle	(degrees)
PHI	Bogie pitch angle (forward pitch is positive)	(degrees)
DEL2	Front suspension deflection (zero when unloaded)	(ft)
DEL3	Middle suspension deflection (zero when unloaded)	(ft)
DEL4	Rear suspension deflection (zero when unloaded)	(ft)
Y2	Terrain elevation under front wheel center	(ft)
Y3	Terrain elevation under middle wheel center	(ft)
Y4	Terrain elevation under rear wheel center	(ft)
YB	Bogie CG displacement	(ft)
FY2	Front suspension force	(lb)
FSY3	Middle suspension force	(lb)
FSY4	Rear suspension force	(lb)
FFS	Front stop force	(lb)
FBS	Rear stop force	(lb)
D2Y0	Hull CG acceleration	(ft/sec^2)
D2YB	Bogie CG acceleration	(ft/sec^2)
D2YW2	Front axle acceleration	(ft/sec^2)
D2YW3	Middle axle acceleration	(ft/sec^2)
D2YW4	Rear axle acceleration	(ft/sec^2)
D2THETA	Hull pitch angular acceleration	(rad/sec^2)
D2PHI	Bogie pitch angular acceleration	(rad/sec^2)

At the end of the simulation, the total computation time needed for the simulation, and to the total number of steps executed are written. A typical printer output appears in Section 2.3.

2.2.2.2 Plotter Output

Plotter output depends on the information supplied by the user on card no. 56. Any of the 31 variables summarized in Table 3 can be plotted against distance travelled or time. Additional variables, up to a total of 40 variables, can be plotted by simply adding them to the list in subroutine PSTORE. Care should, however, be taken to make the additional variables available to the subroutine PSTORE through COMMON statements.

The plots are self-scaled and of 6 x 5 inches in size. They have a variable number written on their Y axis which is keyed to the number in Table 3. A typical plot is shown in Section 2.3.

2.2.2.3 Punched Output

The program generates punched output of the time and axle displacement data for use in creating records of shaker input signals. The variables are punched in the following order and format:

Variables	Format
Two sets of:	
Time, YW2 (front axle displacement),	F7·4,3F8·5,
YW3 (middle axle displacement),	F7·4,3F8·5
and YW4 (rear axle displacement)	

At the end of the output, the program punches a series of minus ones to indicate end of the record to the control system in the second step (see 3.2.1). The punched output can later be converted to those on paper tapes according to equipment availability at the user's installation. If the paper tape size is not large enough to include the complete record, the transfer can be continued on the second paper tape by punching a series of minus ones at the end of the first tape.

2.2.3 Diagnostic Message

If the length of the terrain supplied by the user is insufficient, the program terminates with a diagnostic message "TERRAIN LENGTH INSUFFICIENT".

In such a case, the terrain length has to be increased to at least the length of the truck.

2.3 Illustrative Example

The computer program is used to simulate operation of a loaded M-809 truck operating at 18 mph over a 500 foot long track of 1 inch rms roughness. The program employs the point contact model to simulate the operation and the terrain elevation data used in the simulation have been obtained from the associated program, GRND, described in Appendix A.3. The following lists these terrain data along with the vehicle and tire data used to execute the simulation. The output of the program is in three forms: a. printout, b. plots, and c. punched card deck (axle displacement records). Of these, the printout and plots are included in this section. The punched deck contains the same information as that shown in the plots.

Input: Data Cards (Card 1 to 57) (See 2.2.1)

IBM FORTRAN Coding Form — GX28-7327-6 U/M050, Printed in U.S.A.

```
                         VEHICLE DYNAMIC  ANALYSIS
                              PROGRAM TIRE
                   DYNAMIC SIMULATION OF HEAVE PITCH MOTION
                  THIS PROGRAM SIMULATES HEAVE PITCH
                  MOTION OF A THREE AXLE VEHICLE OPERATING
                  OVER A SPECIFIED PROFILE
                   VEHICLE TYPE            - 5 TON TRUCK
                   TIRE TYPE               - GOODYEAR 11.00-18
                   TERRAIN NO.             - 2 (RANDOM PROFILE)
TIRE MODEL NUMBER                              1
FORWARD SPEED                 18.0         MPH
TERRAIN ROUGHNESS             1.0          INCH RMS
                        VEHICLE FRAME PARAMETERS
MASS OF HULL                  718.6        SLUGS
BOGIE MASS                    6.0          SLUGS
FRONT UNSPRUNG MASS (EACH)    40.59        SLUGS
MIDDLE UNSPRUNG MASS (EACH)   42.09        SLUGS
REAR UNSPRUNG MASS (EACH)     43.65        SLUGS
PITCH INERTIA OF HULL         34924.       SLUG FT SQ
PITCH INERTIA OF BOGIE        3.0          SLUG FT SQ
FRONT SUSP TO HULL CG         12.50        FT
BOGIE CONNECTION TO HULL CG   2.417        FT
HULL CG HEIGHT                0.0          FT
OFFSET,BOG CONN TO HULL PLANE 0.0          FT
```

*A standard card form, IBM electro 888157, is available for punching statements from this form

IBM

FORTRAN Coding Form

GX28-7327-6 U/M050
Printed in U.S.A.

PROGRAM | PROGRAMMER | DATE | PUNCHING INSTRUCTIONS: GRAPHIC / PUNCH | PAGE OF | CARD ELECTRO NUMBER

FORTRAN STATEMENT

```
BOG CONN TO FRNT STOP             2.208       FT
BOG CONN TO REAR STOP             2.208       FT
OFFSET,BOG CON TO BOG CG          0.0         FT
HALF BOGIE LENGTH                 2.208       FT
STOP SIZE                         0.25        FT
STIFFNESS FACTOR,BOG-STOP         10.
STIFFNESS FACTOR,BOG-HULL         1000.
STOP GAP                          0.393       FT
                                       SUSPENSION PARAMETERS
                                              FRONT SUSPENSION,EACH
STIFFNESS                         29976.      LB/FT
VISCOUS DAMPING COEFF.(JOUNCE)    185.        LB SEC/FT
VISCOUS DAMPING COEFF.(RBND)      600.        LB SEC/FT
JOUNCE TRAVEL                     0.5         FT
REBOUND TRAVEL                    0.5         FT
                                              MIDDLE AND REAR SUSPENSIONS
STIFFNESS                         87000.      LB/FT
JOUNCE TRAVEL                     0.7         FT
REBOUND TRAVEL                    0.7         FT
STOP STIFFNESS FACTOR             10.
                                       TIRE PARAMETERS
STIFFNESS                         39000.      LB/FT
DAMPING                           31.1        LB SEC/FT
TIRE RADIUS                       1.67        FT
```

*A standard card form, IBM electro 888157, is available for punching statements from this form

IBM — FORTRAN Coding Form — GX28-7327-6 U/M050 Printed in U.S.A.

PROGRAM | PROGRAMMER | DATE | PUNCHING INSTRUCTIONS: GRAPHIC / PUNCH | PAGE OF | CARD ELECTRO NUMBER*

FORTRAN STATEMENT

```
TIRE CONTACT LENGTH            1.03      FT
TIRE EFFECTIVE WIDTH           0.519     FT
TIRE CUBIC STIFFNESS           17.09     LB/CU IN
TIRE CUBIC DAMPING             57.88     LB SEC/CU FT
TIRE PRESSURE                  30.0      PSI
TIRE STIFFNESS FACTOR          10.
NUMBER OF STEPS TO PRINTING                   25
       1 1 1                             1          0.0         500.0
0.1          5000
```

Next 625 Cards have Profile Elevation Data in 8E10.3 Format, as shown in the following pages

*A standard card form, IBM electro 888157, is available for punching statements from this form

Input: Data Cards (Card No. 58 and onwards)

Profile Elevation Data in 8E10·3 Format

Card No. 58 →	7.72800E-01	7.12400E-01	6.10400E-01	7.89100E-01	8.72800E-01	1.11700E+00	1.29900E+00	1.79800E+00
Card No. 59 →	1.87100E+00	2.09000E+00	2.00700E+00	1.03700E+00	1.74000E+00	1.94600E+00	2.24100E+00	2.28600E+00
etc.	2.34400E+00	2.32200E+00	1.88400E+00	1.67700E+00	1.70100E+00	1.72500E+00	1.61300E+00	1.70100E+00
	1.33600E+00	1.26500E+00	1.15500E+00	1.12900E+00	9.16900E-01	7.50300E-01	7.70200E-01	9.06600E-01
	1.11200E+00	1.25700E+00	1.48200E+00	1.67700E+00	1.81900E+00	1.75600E+00	1.64600E+00	1.60600E+00
	1.80800E+00	2.15000E+00	2.28500E+00	2.28100E+00	2.47000E+00	2.42700E+00	2.66000E+00	2.53700E+00
	2.70000E+00	2.35400E+00	2.38100E+00	2.47900E+00	2.35800E+00	2.74300E+00	2.73200E+00	2.68200E+00
	2.63300E+00	2.58400E+00	2.54100E+00	2.78400E+00	2.64600E+00	2.96200E+00	2.97100E+00	2.80400E+00
	2.65400E+00	2.68600E+00	2.65400E+00	2.47000E+00	2.19300E+00	1.89800E+00	2.22000E+00	2.27300E+00
	1.89900E+00	1.61300E+00	1.67700E+00	1.80000E+00	1.60100E+00	1.66800E+00	1.74600E+00	1.63300E+00
	1.45500E+00	1.58700E+00	1.77500E+00	1.86600E+00	2.00000E+00	2.01100E+00	1.93700E+00	1.75500E+00
	1.66300E+00	1.52200E+00	1.40100E+00	1.38500E+00	1.39500E+00	1.65400E+00	1.80400E+00	1.60500E+00
	1.71300E+00	1.65400E+00	1.65700E+00	1.61500E+00	1.86800E+00	1.56800E+00	1.54500E+00	1.47400E+00
	1.45200E+00	1.49100E+00	1.64000E+00	1.76700E+00	1.42800E+00	1.54600E+00	1.60000E+00	1.77800E+00
	1.90700E+00	1.76800E+00	1.75800E+00	1.48900E+00	1.44800E+00	1.24200E+00	1.03900E+00	9.06600E-01
	1.03000E+00	7.13700E-01	6.54000E-01	1.19800E-01	2.51600E-01	1.31000E-01	1.59400E-01	2.68000E-01

1.00100E-01	-9.68500E-02	-1.15200E-02	-1.33600E-01	-3.27400E-01	-3.44300E-01	-4.30000E-01	-4.34100E-01
-2.13200E-01	-2.52200E-01	-2.08000E-01	-9.71600E-02	-1.63400E-01	-5.32200E-03	-5.42600E-03	1.81400E-02
1.52100E-02	5.73700E-02	-1.14000E-01	-3.93800E-02	-6.44200E-02	-1.30700E-01	-1.25100E-01	-2.14500E-01
-1.64500E-01	-3.06900E-01	-3.84400E-01	-7.55600E-01	-1.01400E+00	-9.95700E-01	-9.75300E-01	-9.12600E-01
-1.04200E+00	-8.89900E-01	-7.99100E-01	-4.96200E-01	-2.91100E-01	-3.44700E-01	-2.98700E-01	-7.71600E-04
3.88100E-01	1.16800E-01	2.96500E-01	1.94800E-01	1.12200E-02	-2.60800E-01	-1.93600E-01	-2.43300E-01
-4.16100E-01	-6.14300E-01	-4.08000E-01	-2.57900E-01	-1.78800E-01	-5.22900E-01	-5.70100E-01	-2.60200E-01
-5.05700E-01	-5.37300E-01	-4.04100E-01	-3.08800E-01	-1.84700E-01	-3.51600E-01	-4.39100E-01	-6.14400E-01
-6.08300E-01	-3.63800E-01	-5.46300E-01	-6.04600E-01	-7.16600E-01	-8.26400E-01	-1.10600E+00	-1.09400E+00
-1.07200E+00	-8.53000E-01	-7.88700E-01	-9.70300E-01	-1.08400E+00	-1.32100E+00	-1.17200E+00	-8.99600E-01
-9.73900E-01	-1.13700E+00	-1.20900E+00	-1.49200E+00	-1.66100E+00	-1.29900E+00	-1.40000E+00	-1.25400E+00
-1.24400E+00	-1.24500E+00	-1.17300E+00	-9.87200E-01	-8.24400E-01	-7.85100E-01	-7.52000E-01	-6.18400E-01
-3.84000E-01	-2.06600E-01	-4.12700E-01	-4.63700E-01	-7.49300E-01	-7.54700E-01	-9.19000E-01	-7.20400E-01
-6.64000E-01	-4.13700E-01	-4.43900E-01	-4.57000E-01	-5.12900E-01	-5.96000E-01	-7.21700E-01	-9.06200E-01
-1.16700E+00	-1.18800E+00	-1.21400E+00	-1.35500E+00	-1.32900E+00	-1.67400E+00	-1.69000E+00	-1.53800E+00
-1.49600E+00	-1.44600E+00	-1.62300E+00	-1.50800E+00	-1.69400E+00	-1.64300E+00	-1.42500E+00	-1.63600E+00
-1.45100E+00	-1.23600E+00	-1.14100E+00	-1.14500E+00	-1.00900E+00	-1.05100E+00	-1.06400E+00	-1.06000E+00
-1.03800E+00	-9.78800E-01	-1.03900E+00	-8.75300E-01	-8.17900E-01	-7.69300E-01	-8.94700E-01	-9.38100E-01
-9.36600E-01	-1.13600E+00	-1.45900E+00	-1.30400E+00	-9.87600E-01	-8.53200E-01	-6.91300E-01	-9.02100E-02
-1.49200E-01	-1.96200E-01	-8.20800E-01	-7.38800E-01	-6.78200E-01	-6.38300E-01	-5.93900E-01	-4.19000E-01
-4.84600E-01	-4.16000E-01	-1.99900E-01	-3.43100E-01	-2.01800E-01	-2.14100E-01	-3.58100E-01	-4.45200E-01
-2.68600E-01	-5.31600E-01	-7.43200E-01	-7.02500E-01	-5.61500E-01	-5.40000E-01	-7.04800E-01	-8.07400E-01
-8.68800E-01	-5.99800E-01	-5.77900E-01	-6.09600E-01	-9.62200E-01	-1.06300E+00	-8.27200E-01	-1.10000E+00
-1.12000E+00	-1.34000E+00	-1.35000E+00	-1.23700E+00	-1.36300E+00	-1.36200E+00	-1.35400E+00	-1.44500E+00
-1.43800E+00	-1.57000E+00	-1.54700E+00	-1.67600E+00	-1.59200E+00	-1.57700E+00	-1.49500E+00	-1.40500E+00
-1.03900E+00	-9.97800E-01	-9.11200E-01	-9.41600E-01	-1.08000E+00	-8.64700E-01	-7.92700E-01	-7.02000E-01
-4.48800E-01	1.08500E-02	1.99400E-01	2.70100E-01	4.99900E-01	2.85900E-01	3.40500E-01	1.25000E-01
2.89600E-01	1.13500E-01	2.15700E-01	1.84700E-01	9.29000E-02	7.91400E-02	2.83000E-01	3.74300E-01
5.01400E-01	6.90100E-01	7.97900E-01	1.17500E+00	1.03900E+00	9.72000E-01	8.01800E-01	7.57900E-01
6.77700E-01	8.83600E-01	7.65800E-01	5.82900E-01	6.14400E-01	6.92600E-01	1.06400E+00	1.26600E+00
1.47600E+00	1.73000E+00	1.76800E+00	1.59900E+00	1.76100E+00	2.10700E+00	1.92200E+00	1.65500E+00
1.78900E+00	1.33500E+00	1.47000E+00	1.48700E+00	1.75200E+00	1.60800E+00	1.25100E+00	1.07100E+00
1.09000E+00	1.17900E+00	1.40600E+00	1.38200E+00	1.43400E+00	1.66900E+00	1.55800E+00	1.38500E+00
1.62300E+00	1.68300E+00	1.73200E+00	1.44600E+00	1.61300E+00	1.36700E+00	1.24100E+00	9.68700E-01
8.99600E-01	9.53100E-01	9.60100E-01	9.24900E-01	7.31100E-01	6.68100E-01	3.79200E-01	2.82100E-01
1.44300E-01	4.44200E-03	5.21900E-03	1.52800E-01	3.12500E-02	1.59700E-01	2.26800E-01	1.89600E-01
2.04700E-01	1.69400E-01	2.51200E-01	1.67000E-01	5.22200E-02	-1.38100E-02	3.32500E-03	1.32800E-01
-1.40400E-01	-3.72100E-01	-3.22000E-01	-1.78700E-01	-3.60300E-01	-5.49400E-01	-6.30600E-01	-6.92300E-01
-3.30900E-01	-2.58200E-01	-3.07400E-01	-4.67100E-01	-6.19500E-01	-4.04400E-01	-5.57000E-01	-6.40200E-01
-9.16800E-01	-6.30000E-01	-6.55400E-01	-6.84000E-01	-6.62200E-01	-9.06000E-01	-9.88800E-01	-8.94800E-01
-1.01600E+00	-8.62600E-01	-6.77200E-01	-7.18800E-01	-5.38800E-01	-5.64300E-01	-6.66500E-01	-4.21200E-01
-4.95800E-01	-3.75600E-01	-2.05900E-01	4.24000E-02	-4.26500E-03	-3.14700E-01	-3.03100E-01	-3.21200E-01
-2.76200E-01	-2.21900E-01	3.09700E-02	-2.09000E-01	-3.43600E-01	-2.02800E-01	-1.76400E-01	-3.26900E-01
-2.61300E-01	-2.67300E-01	-5.05100E-01	-6.52000E-01	-7.71300E-01	-7.21500E-01	-8.87600E-01	-8.18800E-01
-1.13900E+00	-1.11300E+00	-1.04500E+00	-1.25900E+00	-1.34400E+00	-1.22700E+00	-1.05300E+00	-9.87700E-01
-1.11200E+00	-1.10000E+00	-1.29800E+00	-1.31400E+00	-1.50400E+00	-1.09400E+00	-1.05900E+00	-9.11100E-01
-9.25500E-01	-6.12700E-01	-5.75600E-01	-7.95400E-01	-8.80000E-01	-9.11900E-01	-9.25500E-01	-8.23600E-01
-9.84000E-01	-8.77500E-01	-9.44400E-01	-9.37300E-01	-9.88700E-01	-7.82400E-01	-5.50100E-01	-4.09000E-01
-2.48000E-01	-2.25100E-01	-1.96000E-01	-4.14300E-02	3.23400E-02	-3.39500E-01	-2.18200E-01	-4.34300E-01
-2.63900E-01	-2.27700E-01	-4.37200E-01	-3.23000E-01	-5.19800E-01	-8.80200E-01	-9.68000E-01	-7.88700E-01
-9.23700E-01	-8.63300E-01	-8.88500E-01	-7.07000E-01	-5.93700E-01	-4.71500E-01	-4.54900E-01	-4.78800E-01
-6.05900E-01	-7.42400E-01	-4.32400E-01	-2.38400E-01	2.41100E-01	2.02200E-01	1.39500E-01	1.93300E-02
-6.71600E-02	1.89000E-01	2.09300E-01	5.55100E-04	-1.31300E-01	-8.94700E-02	-5.85900E-02	-1.66000E-01
1.19900E-01	2.22800E-01	2.50800E-01	2.25800E-01	-9.86600E-02	-6.44600E-01	-7.70100E-01	-4.28200E-01
-6.06800E-01	-6.45200E-01	-5.61500E-01	-3.24000E-01	-1.52200E-01	-1.41300E-01	-1.20200E-01	-3.68400E-01
-2.78200E-01	-3.16200E-01	-3.13900E-01	-3.30900E-01	-2.94500E-01	-2.35100E-01	-8.97100E-02	-8.19800E-02
-1.88300E-01	-2.04600E-01	-3.44300E-01	4.87700E-02	1.08100E-01	3.78400E-01	4.09400E-01	3.91000E-01
2.72100E-01	1.16600E-01	3.94200E-01	3.40000E-01	1.34100E-01	2.47800E-02	1.44900E-01	-9.10400E-02
-4.80300E-02	-5.60700E-01	-3.55500E-01	-3.22100E-01	-3.47500E-01	-3.84000E-01	-1.55900E-01	-2.75500E-01
-2.91800E-01	-2.13000E-01	-8.06400E-02	2.14800E-02	1.70100E-01	5.14300E-03	3.82700E-01	3.63500E-01
4.29000E-01	5.75300E-01	6.30100E-01	8.31200E-01	8.67600E-01	1.00800E+00	8.87700E-01	6.91200E-01

5.21900E-01	4.26000E-01	4.42700E-01	5.06000E-01	8.32300E-01	7.19700E-01	7.61000E-01	8.39800E-01
1.03200E+00	8.72300E-01	5.90700E-01	4.61200E-01	3.43300E-01	4.40400E-01	2.51100E-01	3.22500E-01
4.68800E-01	5.23900E-01	4.46500E-01	7.85500E-01	9.54700E-01	9.68400E-01	1.01900E+00	9.66000E-01
9.06000E-01	7.15000E-01	9.27000E-01	7.28700E-01	7.45600E-01	1.02700E+00	1.05800E+00	1.06800E+00
1.31800E+00	1.49500E+00	1.68000E+00	1.89800E+00	2.13000E+00	2.24800E+00	2.00200E+00	2.01100E+00
1.96300E+00	1.97300E+00	2.13900E+00	2.07300E+00	1.99500E+00	1.68400E+00	1.54700E+00	1.62400E+00
1.40200E+00	1.46700E+00	1.53900E+00	1.70700E+00	1.63200E+00	1.67900E+00	1.54500E+00	1.55700E+00
2.00200E+00	1.77100E+00	1.94800E+00	2.13700E+00	2.35500E+00	2.36500E+00	2.07400E+00	1.64300E+00
1.62800E+00	1.70300E+00	1.59400E+00	1.57400E+00	1.39500E+00	1.33800E+00	1.41800E+00	1.55300E+00
1.54900E+00	1.32300E+00	1.21100E+00	1.23400E+00	1.18300E+00	1.06000E+00	1.13300E+00	1.42200E+00
1.44800E+00	1.44000E+00	1.33300E+00	1.51700E+00	1.42200E+00	1.35400E+00	9.84200E-01	1.21000E+00
9.44400E-01	9.63000E-01	1.11800E+00	1.25600E+00	1.13300E+00	1.03300E+00	9.74800E-01	1.23600E+00
1.45400E+00	1.58800E+00	1.37800E+00	1.02700E+00	8.63600E-01	7.92800E-01	7.42300E-01	8.99400E-01
5.86000E-01	7.82100E-01	7.06800E-01	5.70800E-01	7.07300E-01	8.00900E-01	8.22300E-01	6.30000E-01
9.10700E-01	8.73300E-01	6.51800E-01	5.96600E-01	6.38500E-01	6.46700E-01	3.87200E-01	2.33700E-01
-2.94200E-02	-9.62600E-02	8.74400E-02	1.46500E-01	3.17900E-01	2.53600E-01	1.19800E-01	-1.11600E-01
-3.35300E-01	-1.82900E-01	1.13500E-02	-1.80100E-01	-1.52800E-01	1.33100E-01	-1.33200E-01	-4.29300E-02
-1.08500E-01	-8.20400E-02	-3.22400E-02	2.76200E-01	2.93200E-01	3.89400E-01	3.65600E-01	2.89500E-01
3.29300E-01	2.11100E-01	1.62400E-01	-9.24900E-02	-1.13900E-01	-3.01300E-01	-2.04100E-01	-2.30900E-01
-2.82200E-01	-3.23200E-01	-4.85500E-01	-3.31600E-01	-2.78300E-01	-1.91200E-01	-1.80500E-01	-1.73500E-01
-3.60300E-01	-1.77800E-01	-3.73400E-01	-4.56300E-01	-3.06300E-01	-4.28500E-01	-4.77000E-01	-5.16800E-01
-4.23100E-01	-2.43000E-01	-5.32600E-01	-5.04300E-01	-5.06500E-01	-2.35000E-01	-2.29400E-01	-5.67800E-01
-5.84300E-01	-7.29200E-01	-7.87400E-01	-9.54700E-01	-8.57200E-01	-1.02700E+00	-1.00800E+00	-8.49200E-01
-9.44100E-01	-1.04700E+00	-1.05400E+00	-7.56800E-01	-3.37200E-01	-1.81300E-01	-2.25200E-01	-1.05600E-01
3.39100E-02	-2.50600E-01	-5.96200E-01	-8.46200E-01	-6.59900E-01	-9.07600E-01	-5.81300E-01	-7.67100E-01
-6.79900E-01	-7.03000E-01	-5.14400E-01	-7.47700E-01	-7.92200E-01	-9.33700E-01	-7.84800E-01	-6.59000E-01
-6.27800E-01	-2.12500E-01	-2.40000E-01	-4.42100E-01	-4.19500E-01	-2.01800E-01	-3.06400E-01	-3.63500E-01
-4.33[illegible]00E-01	-6.42600E-01	-5.66700E-01	-3.74400E-01	-4.00500E-01	-2.19400E-01	3.24000E-02	-2.38000E-02
-2.29600E-01	-2.65400E-01	-3.08600E-01	-3.25700E-01	-4.97500E-01	-4.74400E-01	-2.77600E-01	-6.14200E-01
-3.88600E-01	-5.80200E-01	-6.20100E-01	-7.53000E-01	-1.05400E+00	-9.38300E-01	-8.11600E-01	-7.37500E-01
-9.11900E-01	-9.51400E-01	-1.02400E+00	-9.74200E-01	-8.08800E-01	-9.02200E-01	-1.15600E+00	-1.51300E+00
-1.64300E+00	-1.82500E+00	-1.68800E+00	-1.68300E+00	-1.66500E+00	-1.90300E+00	-1.75100E+00	-1.81200E+00
-1.68800E+00	-1.56300E+00	-1.61100E+00	-1.41800E+00	-1.31500E+00	-1.16200E+00	-1.08100E+00	-1.08200E+00
-1.11400E+00	-9.33500E-01	-6.66600E-01	-5.45700E-01	-3.76100E-01	-1.90600E-01	-6.72300E-02	-3.91100E-01
-5.01500E-01	-7.40000E-01	-8.60300E-01	-8.33700E-01	-7.87200E-01	-5.75500E-01	-5.47300E-01	-9.16300E-01
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-3.98700E-01	-2.01100E-01	-3.38000E-01	-8.04500E-01	-1.16400E+00	-9.59800E-01	-1.04800E+00	-1.14300E+00
-1.34600E+00	-1.44600E+00	-1.57400E+00	-1.40300E+00	-1.66000E+00	-1.93900E+00	-1.89100E+00	-1.97900E+00
-1.99400E+00	-2.14000E+00	-1.85700E+00	-1.60800E+00	-1.42800E+00	-1.33000E+00	-1.29200E+00	-1.25900E+00
-1.38900E+00	-1.57500E+00	-1.54500E+00	-1.38300E+00	-1.65000E+00	-1.69000E+00	-1.59500E+00	-1.62300E+00
-1.70500E+00	-1.89400E+00	-1.80000E+00	-1.76400E+00	-1.60600E+00	-1.55700E+00	-1.65200E+00	-1.59200E+00
-1.75200E+00	-1.63200E+00	-1.63900E+00	-1.48000E+00	-1.40700E+00	-1.06300E+00	-9.06600E-01	-5.87400E-01
-3.05100E-01	-3.29500E-01	-2.01400E-01	-3.63400E-02	5.86800E-02	2.18000E-01	1.71400E-01	3.12300E-01
1.93400E-01	4.71700E-01	4.93200E-01	7.00700E-01	1.01700E+00	1.14000E+00	1.46200E+00	1.79600E+00
1.67900E+00	1.68000E+00	1.54100E+00	1.13600E+00	9.79000E-01	7.19700E-01	8.41500E-01	9.97600E-01
9.00000E-01	8.08900E-01	8.00400E-01	7.66100E-01	4.32600E-01	7.01300E-01	6.19500E-01	6.03400E-01
2.17300E-01	3.65900E-01	5.82000E-01	5.53300E-01	5.18300E-01	5.80400E-01	4.03200E-01	3.55700E-01
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3.62000E-02	2.18600E-01	2.96800E-01	1.14100E-01	1.59800E-01	-1.74600E-01	2.26400E-02	2.45300E-01
3.68200E-01	2.54300E-01	1.74900E-01	2.03100E-01	1.85100E-01	-1.21800E-01	-1.83300E-01	9.92700E-02
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4.86600E-01	6.69100E-01	7.46200E-01	7.16900E-01	7.67800E-01	4.24500E-01	4.62700E-01	4.13400E-01
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3.35300E-01	2.64300E-01	2.23900E-01	-1.21000E-01	5.50600E-02	1.10400E-01	3.28800E-01	5.17100E-01
4.10900E-01	4.42100E-01	2.76600E-01	3.83200E-01	5.91600E-01	7.57600E-01	8.37700E-01	8.79400E-01
1.05700E+00	7.06900E-01	8.10900E-01	9.55500E-01	1.11000E+00	8.73800E-01	1.04100E+00	8.27100E-01
4.70400E-01	3.92100E-01	6.69000E-01	9.54300E-01	1.13700E+00	1.29000E+00	1.25700E+00	1.14100E+00

1.14400E+00	1.05900E+00	8.93900E-01	1.06400E+00	1.05500E+00	1.03500E+00	1.34300E+00	1.24300E+00
1.34900E+00	1.00600E+00	9.03800E-01	7.80500E-01	5.29900E-01	3.15200E-01	1.56900E-01	2.13100E-01
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9.23800E-02	1.54600E-01	1.48800E-01	2.04500E-01	8.68600E-03	2.76000E-01	2.35300E-01	1.16900E-01
3.29300E-03	2.19100E-01	-1.54100E-01	-8.43200E-02	4.60600E-02	-1.09200E-01	-1.13100E-02	-1.51900E-01
1.19800E-01	2.07900E-01	2.07900E-01	1.81100E-01	6.67600E-02	-1.53200E-01	-2.26300E-01	-1.61400E-01
-1.36200E-01	-3.31900E-01	-5.88500E-01	-4.56500E-01	4.45800E-02	2.04600E-01	5.56200E-02	-5.14500E-02
9.01800E-02	1.62500E-01	2.19000E-01	6.37300E-02	9.46000E-02	1.63000E-01	7.08400E-02	-9.53800E-02
-8.14900E-02	-8.88900E-02	-1.20200E-01	-3.30000E-02	-2.86600E-01	9.61400E-02	2.90800E-01	5.85600E-01
6.13400E-01	7.33100E-01	9.32800E-01	7.84500E-01	9.02100E-01	1.12700E+00	9.13600E-01	9.60200E-01
1.02700E+00	9.10800E-01	5.63700E-01	6.02100E-01	4.79800E-01	6.01900E-01	6.54100E-01	9.20100E-01
9.64800E-01	1.08100E+00	1.18800E+00	1.24300E+00	1.13100E+00	8.49000E-01	8.34600E-01	1.00600E+00
1.22800E+00	1.40200E+00	1.21200E+00	1.17800E+00	1.05800E+00	1.23800E+00	9.70100E-01	8.95600E-01
8.59900E-01	4.70000E-01	4.04400E-01	4.17600E-01	2.55900E-01	2.53400E-01	6.24100E-02	-2.11500E-02
1.47100E-01	1.94300E-01	9.72200E-02	2.82900E-01	2.69600E-01	2.38100E-01	1.93600E-01	5.03800E-01
6.04700E-01	8.94900E-01	1.08800E+00	1.26400E+00	1.11400E+00	9.89300E-01	1.14900E+00	1.07100E+00
1.23100E+00	1.26400E+00	1.53000E+00	1.31300E+00	1.66600E+00	1.86300E+00	1.98800E+00	2.12700E+00
2.02500E+00	2.21700E+00	2.36400E+00	2.18200E+00	2.13100E+00	2.08800E+00	1.99400E+00	1.82700E+00
1.61800E+00	1.53000E+00	1.34500E+00	1.14100E+00	1.08100E+00	1.05400E+00	8.58300E-01	8.29800E-01
7.50100E-01	1.13800E+00	1.20000E+00	1.11800E+00	1.01500E+00	9.04000E-01	6.08100E-01	5.34000E-01
9.15200E-01	9.29700E-01	9.99600E-01	9.18900E-01	7.13900E-01	8.14200E-01	8.39400E-01	9.44500E-01
8.58700E-01	1.12800E+00	1.26000E+00	1.08800E+00	9.57700E-01	1.19500E+00	1.36100E+00	1.31300E+00
9.26800E-01	7.42300E-01	8.07500E-01	5.00700E-01	7.42500E-01	5.99000E-01	8.91800E-01	1.16700E+00
1.51700E+00	1.07200E+00	9.14900E-01	7.26200E-01	6.95600E-01	8.55000E-01	8.30700E-01	6.80200E-01
5.36300E-01	4.70200E-01	3.70900E-01	3.03800E-01	3.89200E-01	2.21200E-01	2.09900E-01	4.81900E-02
-7.70400E-02	-1.12200E-01	-3.98800E-01	-5.52500E-01	-6.62400E-01	-6.18200E-01	-3.35400E-01	-3.61400E-01
-1.30300E-01	6.06500E-02	-7.95200E-02	-2.69900E-01	1.31700E-01	-5.09300E-02	-1.02700E-01	-4.12500E-01
-4.21000E-01	-5.42100E-01	-5.62900E-01	-4.74600E-01	-5.19300E-01	-4.10400E-01	-3.34200E-01	-1.08600E-01
-1.68300E-01	-2.31000E-01	-3.53800E-01	-5.04600E-01	-5.94100E-01	-8.54600E-01	-9.28600E-01	-8.44900E-01
-8.96900E-01	-8.71400E-01	-7.70800E-01	-1.06700E+00	-1.07600E+00	-1.17100E+00	-1.02500E+00	-8.65200E-01
-1.04600E+00	-1.09300E+00	-1.20400E+00	-1.04000E+00	-1.29200E+00	-1.26000E+00	-1.13700E+00	-1.24900E+00
-1.26200E+00	-9.57500E-01	-6.82100E-01	-7.55500E-01	-9.15300E-01	-1.17400E+00	-1.21900E+00	-1.28900E+00
-1.40100E+00	-1.27700E+00	-1.24500E+00	-1.18700E+00	-9.05500E-01	-9.13700E-01	-7.49200E-01	-7.80500E-01
-6.22200E-01	-8.81200E-01	-5.84500E-01	-5.65800E-01	-6.20900E-01	-4.65900E-01	-1.92500E-01	-4.01600E-01
-5.94700E-01	-6.63400E-01	-7.25900E-01	-5.90700E-01	-8.33100E-01	-7.41500E-01	-7.51500E-01	-6.69800E-01
-4.33800E-01	-3.59500E-01	-2.41000E-01	-1.81100E-01	-4.84300E-01	-6.06000E-01	-5.23300E-01	-4.24700E-01
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-8.55900E-01	-7.59500E-01	-9.92900E-01	-9.82700E-01	-1.07300E+00	-1.01600E+00	-7.43600E-01	-1.03200E+00
-1.05300E+00	-8.05900E-01	-7.96100E-01	-8.93400E-01	-1.15700E+00	-1.09500E+00	-1.21400E+00	-1.23200E+00
-1.30800E+00	-1.03500E+00	-8.31800E-01	-7.52500E-01	-7.50100E-01	-9.06500E-01	-1.15800E+00	-1.27500E+00
-1.07500E+00	-9.65300E-01	-9.39800E-01	-9.22500E-01	-1.18100E+00	-9.81400E-01	-9.72300E-01	-1.01300E+00
-1.14400E+00	-1.29100E+00	-1.50100E+00	-1.38200E+00	-1.24900E+00	-1.25900E+00	-1.25400E+00	-1.14700E+00
-1.06000E+00	-1.09800E+00	-8.92400E-01	-6.60300E-01	-4.71400E-01	-4.43900E-01	-6.38700E-01	-4.25100E-01
-5.80400E-01	-8.50800E-01	-7.23200E-01	-7.17000E-01	-7.81200E-01	-7.69100E-01	-8.74300E-01	-1.16000E+00
-1.39200E+00	-1.56600E+00	-1.42600E+00	-1.44300E+00	-1.49300E+00	-1.82800E+00	-2.04500E+00	-2.02600E+00
-1.81400E+00	-1.72300E+00	-1.74200E+00	-1.20600E+00	-1.52700E+00	-1.38200E+00	-1.34300E+00	-1.10400E+00
-9.29300E-01	-7.69600E-01	-6.33200E-01	-4.76300E-01	-5.40500E-01	-5.90600E-01	-7.14700E-01	-5.77500E-01
-6.16700E-01	-6.98400E-01	-7.50000E-01	-7.15900E-01	-8.54800E-01	-7.08100E-01	-4.67300E-01	-4.15800E-01
-2.25400E-01	-1.06700E-01	1.04900E-02	-8.95500E-02	-4.55400E-02	-4.03600E-01	-6.89700E-01	-5.71300E-01
-4.78500E-01	-6.20100E-01	-8.66100E-01	-1.03000E+00	-9.92400E-01	-9.93700E-01	-1.04300E+00	-8.86200E-01
-8.96400E-01	-1.14100E+00	-9.58400E-01	-1.07000E+00	-8.75300E-01	-7.74600E-01	-4.63500E-01	-5.16900E-01
-3.36900E-01	-2.43900E-01	-2.67500E-01	-5.39300E-01	-6.08600E-01	-6.71500E-01	-4.69900E-01	-2.81200E-01
-4.94100E-01	-1.27900E-01	-1.21700E-02	-8.18300E-02	-4.84000E-01	-7.26900E-01	-6.39300E-01	-4.61700E-01
-2.97700E-01	-5.13100E-01	-3.86200E-01	-5.25600E-01	-4.28000E-01	-3.22100E-01	-6.03500E-01	-7.84000E-01
-8.01700E-01	-8.73700E-01	-7.56000E-01	-9.68000E-01	-7.83400E-01	-8.87300E-01	-1.05400E+00	-9.78000E-01
-7.04800E-01	-7.37000E-01	-5.85400E-01	-3.43500E-01	-3.23700E-01	-2.17400E-01	-1.89000E-01	6.01400E-02
8.31000E-02	2.43000E-01	2.61000E-02	-5.98800E-02	7.93800E-02	9.65700E-02	-8.32800E-03	-5.52200E-02
1.88200E-01	1.93500E-01	2.66800E-01	1.87700E-01	1.85200E-01	-1.24700E-01	-1.87900E-01	-3.94100E-01
-4.71100E-01	-5.36200E-01	-7.61800E-01	-6.05400E-01	-3.26200E-01	-5.21900E-01	-6.86500E-01	-6.75400E-01
-7.26700E-01	-7.02300E-01	-5.58900E-01	-4.15900E-01	-1.51600E-01	-4.36200E-01	-3.38600E-01	-4.99800E-01
-3.54500E-01	-4.44000E-01	-4.25700E-01	-6.44300E-01	-7.71300E-01	-4.89900E-01	-3.23900E-01	-4.01800E-01

-1.96700E-01	-1.80200E-01	-1.45400E-01	-1.12800E-02	4.87500E-01	5.67700E-01	5.99000E-01	7.23400E-01
4.57400E-01	5.77500E-01	3.28600E-01	3.29200E-01	3.25900E-01	3.62000E-01	2.51700E-01	4.46300E-01
4.21700E-01	6.35800E-01	5.90500E-01	5.23900E-01	5.93900E-01	3.91700E-01	2.47600E-01	1.22200E-01
6.67200E-02	1.96300E-01	3.84900E-01	4.01600E-01	1.91800E-01	3.39500E-02	-3.69000E-02	8.66900E-02
4.04400E-02	4.14500E-02	2.21800E-01	5.02700E-01	3.37600E-01	3.09500E-01	5.07100E-01	4.90300E-01
5.06500E-01	5.07600E-01	4.74600E-01	3.68700E-01	3.20500E-01	3.06500E-01	2.39000E-01	2.68500E-01
3.11900E-01	1.54000E-01	-1.16300E-01	3.26900E-01	6.16800E-01	1.08700E+00	1.23600E+00	9.45300E-01
1.05000E+00	1.12900E+00	1.13700E+00	1.00900E+00	9.89000E-01	1.15500E+00	1.22900E+00	1.33000E+00
1.19500E+00	1.50900E+00	1.72500E+00	1.94300E+00	2.27300E+00	2.37800E+00	2.33300E+00	2.09400E+00
2.03700E+00	2.04800E+00	1.89300E+00	1.76300E+00	1.92100E+00	2.32700E+00	2.43200E+00	2.23100E+00
2.32900E+00	2.42900E+00	2.12800E+00	2.37300E+00	2.22400E+00	1.86700E+00	1.59900E+00	1.51100E+00
1.46700E+00	1.58600E+00	1.60600E+00	1.65300E+00	1.47400E+00	1.46700E+00	1.41400E+00	1.41500E+00
1.43000E+00	1.66700E+00	1.49200E+00	1.49400E+00	1.39900E+00	1.59900E+00	1.29700E+00	1.19600E+00
8.16900E-01	8.52500E-01	9.62000E-01	8.90600E-01	7.64200E-01	6.68600E-01	5.87400E-01	3.78200E-01
5.20300E-01	3.76100E-01	4.94400E-01	3.52400E-01	1.67700E-01	2.25300E-01	1.87600E-01	3.19700E-01
5.63400E-01	6.88700E-01	9.36600E-01	8.55500E-01	1.07800E+00	1.05600E+00	9.28600E-01	1.00600E+00
1.19900E+00	1.25100E+00	1.33400E+00	1.57300E+00	1.41500E+00	1.46400E+00	1.71800E+00	1.76500E+00
1.79200E+00	1.66400E+00	1.52900E+00	1.53700E+00	1.36100E+00	1.04200E+00	9.15300E-01	6.97800E-01
7.70300E-01	7.61000E-01	9.41200E-01	1.11500E+00	1.18200E+00	1.22600E+00	1.06900E+00	1.40700E+00
1.74800E+00	2.01800E+00	2.18000E+00	2.27700E+00	2.16500E+00	2.40100E+00	2.31700E+00	2.13400E+00
2.12800E+00	1.88900E+00	1.90500E+00	1.70800E+00	1.64700E+00	1.41000E+00	1.53900E+00	1.23100E+00
8.77300E-01	9.83500E-01	1.30000E+00	1.27400E+00	1.08700E+00	1.28700E+00	1.37700E+00	1.13100E+00
9.26200E-01	1.05100E+00	1.23900E+00	1.31900E+00	1.58400E+00	1.56700E+00	1.38700E+00	1.60600E+00
1.42900E+00	1.43200E+00	1.26500E+00	9.45900E-01	9.83400E-01	1.02000E+00	1.24300E+00	1.08900E+00
1.11600E+00	9.80000E-01	1.15400E+00	9.14700E-01	8.36500E-01	5.15000E-01	5.62500E-01	5.08900E-01
5.74600E-01	3.19900E-01	2.97900E-01	1.43800E-01	1.98700E-01	4.25200E-01	2.57100E-01	1.30300E-01
-1.33900E-01	-4.44700E-01	-2.21700E-01	-2.07000E-01	-1.99900E-01	-4.28900E-02	1.87600E-01	-1.65300E-03
-1.71900E-01	-4.30900E-01	-3.77200E-01	-3.91900E-01	-2.30500E-01	-2.04900E-01	-1.99800E-01	5.81500E-03
-1.05100E-02	2.99700E-01	2.95300E-01	3.48700E-01	3.71200E-01	1.90100E-01	2.94500E-02	2.54800E-01
4.07700E-01	4.49700E-01	3.43500E-01	2.17900E-01	-1.12900E-02	1.17900E-01	3.10300E-02	3.53500E-02
3.83700E-02	1.11200E-01	2.17300E-01	3.12200E-01	4.98600E-01	1.87400E-01	2.72400E-01	1.20200E-01
2.23900E-01	2.88900E-01	2.25300E-01	1.62600E-01	1.34200E-01	5.60200E-02	2.49800E-02	-1.08700E-01
-8.81500E-02	-2.05900E-01	-7.27900E-01	-7.07700E-01	-5.34800E-01	-5.07500E-01	-4.86200E-01	-3.78200E-01
-6.98900E-01	-9.69400E-01	-7.87700E-01	-8.69300E-01	-1.01000E+00	-1.14200E+00	-1.04800E+00	-1.14100E+00
-1.63400E+00	-1.82200E+00	-1.93800E+00	-2.09300E+00	-2.21300E+00	-2.29300E+00	-2.17600E+00	-1.95600E+00
-2.25600E+00	-2.34400E+00	-2.22400E+00	-2.19600E+00	-2.03100E+00	-2.09200E+00	-1.91800E+00	-1.67700E+00
-1.66300E+00	-1.70800E+00	-1.83300E+00	-1.70900E+00	-1.87800E+00	-1.74300E+00	-1.72700E+00	-1.75400E+00
-1.60200E+00	-1.51100E+00	-1.49400E+00	-1.23600E+00	-1.00300E+00	-8.83900E-01	-9.04800E-01	-1.01400E+00
-1.37900E+00	-1.25900E+00	-1.32400E+00	-1.07700E+00	-1.22800E+00	-1.36600E+00	-1.50100E+00	-1.32900E+00
-1.35400E+00	-1.38400E+00	-1.39900E+00	-1.24900E+00	-1.42800E+00	-1.33500E+00	-1.46500E+00	-1.65600E+00
-1.61600E+00	-1.63000E+00	-1.62600E+00	-1.58200E+00	-1.68100E+00	-1.66600E+00	-1.73100E+00	-1.74200E+00
-1.92800E+00	-2.12800E+00	-2.14800E+00	-1.90900E+00	-1.67500E+00	-1.83400E+00	-1.90000E+00	-2.20400E+00
-1.95100E+00	-1.77900E+00	-1.79600E+00	-1.79800E+00	-1.64500E+00	-1.77500E+00	-1.63400E+00	-1.61300E+00
-1.79800E+00	-1.56600E+00	-1.55500E+00	-1.43900E+00	-1.59600E+00	-1.42900E+00	-1.32700E+00	-1.59200E+00
-1.52500E+00	-1.34000E+00	-1.56100E+00	-1.59800E+00	-1.57800E+00	-1.49800E+00	-1.65700E+00	-1.44300E+00
-1.36500E+00	-1.34800E+00	-1.29700E+00	-1.13800E+00	-8.91900E-01	-9.90700E-01	-1.27200E+00	-1.45300E+00
-1.53100E+00	-1.69100E+00	-1.56000E+00	-1.37500E+00	-1.37100E+00	-1.12500E+00	-1.08300E+00	-1.08100E+00
-1.13900E+00	-1.42300E+00	-1.49100E+00	-1.12800E+00	-1.14600E+00	-1.25200E+00	-1.30300E+00	-1.05600E+00
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5.34600E-01	6.03000E-01	6.36100E-01	6.65200E-01	6.22300E-01	6.67200E-01	3.73200E-01	1.10700E-01
5.54200E-02	2.11200E-01	5.41700E-02	1.38500E-01	3.46200E-01	3.79700E-01	5.42600E-01	9.26700E-01
1.08700E+00	1.10900E+00	1.44400E+00	1.37600E+00	1.40600E+00	1.27100E+00	1.14700E+00	1.21500E+00
1.06800E+00	1.31500E+00	1.40800E+00	1.14200E+00	9.69400E-01	1.31000E+00	1.46100E+00	1.31700E+00
1.27000E+00	1.14900E+00	1.08100E+00	9.03300E-01	7.11200E-01	3.63200E-01	3.75700E-01	3.35500E-01
5.04500E-01	6.68600E-01	9.06700E-01	9.66800E-01	1.29200E+00	1.32200E+00	1.13800E+00	9.00000E-01
1.06800E+00	8.88300E-01	9.66400E-01	7.43900E-01	7.37400E-01	8.23500E-01	5.93400E-01	7.96100E-01
6.86700E-01	5.09700E-01	1.83000E-01	-5.30400E-02	1.13000E-01	3.84300E-01	4.62200E-01	6.53000E-01

6.17000E-01	3.20300E-01	8.91600E-02	-4.23300E-02	-9.42500E-02	-2.67700E-01	-3.11600E-01	-4.06800E-01
-1.70500E-01	-1.70800E-01	-4.65100E-01	-6.94600E-01	-6.65000E-01	-6.20400E-01	-8.42800E-01	-9.07700E-01
-9.78500E-01	-7.66500E-01	-7.44200E-01	-7.19300E-01	-7.10700E-01	-6.05200E-01	-3.61000E-01	-3.54700E-01
-3.45500E-01	-2.33800E-01	-5.09500E-01	-4.02700E-01	-3.82700E-01	-3.44500E-01	-2.44900E-01	-1.77600E-01
-6.01100E-01	-5.50700E-01	-4.46300E-01	-3.35600E-01	-3.17300E-01	-2.87900E-01	-3.55200E-01	-4.29500E-01
-5.94400E-01	-5.53200E-01	-6.05900E-01	-6.94100E-01	-6.34700E-01	-3.09200E-01	-5.41600E-01	-4.87400E-01
-4.15300E-01	-4.97900E-01	-5.46400E-01	-4.10200E-01	-7.59700E-02	-2.06100E-01	-1.25800E-01	-1.73500E-01
-4.17300E-01	-2.54000E-01	-9.69600E-02	-2.04700E-01	-2.17100E-01	-3.21600E-01	-2.87200E-03	2.09600E-01
1.99700E-01	1.52200E-01	1.18300E-02	4.40300E-02	4.03600E-02	1.77500E-01	3.96900E-01	4.52200E-01
2.25200E-01	1.29900E-01	2.31400E-01	2.28300E-01	2.56600E-01	4.52400E-01	4.55300E-01	4.45300E-01
1.90500E-01	2.57200E-01	2.57200E-01	6.34600E-01	4.70700E-01	5.67200E-01	4.25400E-01	3.07400E-01
2.76900E-01	2.63400E-01	2.71100E-02	-6.16900E-02	8.37900E-03	1.95500E-01	9.40500E-02	-1.34100E-01
-8.43200E-02	4.61700E-02	7.98000E-02	2.33300E-02	-2.37200E-01	-1.90000E-01	-1.28000E-01	-3.54900E-01
-3.07100E-01	-2.47400E-01	-3.11500E-01	-3.00800E-01	-2.32400E-01	-2.31900E-01	-1.34700E-01	-2.61900E-02
-1.13400E-01	2.30600E-01	1.00300E-01	-6.12100E-02	3.82200E-02	1.17400E-01	3.19900E-01	3.43000E-01
3.89700E-01	4.26700E-01	1.90000E-01	-6.27600E-02	-1.43500E-01	-1.22400E-01	1.02700E-01	8.80800E-02
3.92400E-01	2.65200E-01	3.83900E-01	5.98900E-01	3.97400E-01	4.11000E-01	8.26800E-01	1.08900E+00
8.83900E-01	8.87100E-01	1.03000E+00	1.06700E+00	1.06100E+00	9.16500E-01	7.97200E-01	5.27200E-01
7.68800E-01	7.61400E-01	7.47800E-01	4.98100E-01	4.31000E-01	2.52300E-01	2.88300E-01	4.04500E-01
5.16100E-01	4.98200E-01	6.53300E-01	6.89700E-01	8.78400E-01	1.08800E+00	1.00200E+00	1.06900E+00
1.14300E+00	1.14400E+00	1.13100E+00	1.28500E+00	1.12600E+00	1.27500E+00	1.21800E+00	1.41900E+00
1.33700E+00	1.39900E+00	1.71500E+00	2.00100E+00	2.12800E+00	1.91300E+00	1.81200E+00	1.69900E+00
1.83600E+00	1.68800E+00	1.88800E+00	2.05900E+00	1.98600E+00	1.85800E+00	2.08300E+00	1.93800E+00
2.17500E+00	1.95300E+00	1.71700E+00	1.75800E+00	1.56000E+00	1.63900E+00	1.79000E+00	1.77900E+00
1.83700E+00	1.88300E+00	2.19900E+00	2.11400E+00	2.17400E+00	1.87400E+00	1.73800E+00	1.60700E+00
1.66000E+00	1.61500E+00	1.76500E+00	1.54400E+00	1.50500E+00	1.73900E+00	1.95300E+00	1.91200E+00
1.78600E+00	1.67200E+00	1.83200E+00	1.79300E+00	1.51500E+00	1.52600E+00	1.77100E+00	1.90500E+00
1.67000E+00	1.72400E+00	1.54900E+00	1.24600E+00	1.01700E+00	9.30500E-01	7.61900E-01	8.08600E-01
1.08300E+00	1.01700E+00	8.37900E-01	6.57900E-01	8.84200E-01	8.63600E-01	1.22900E+00	1.60500E+00
1.49700E+00	1.36700E+00	1.43600E+00	1.39200E+00	1.25600E+00	1.14000E+00	9.86500E-01	1.03400E+00
9.63200E-01	1.01500E+00	1.06300E+00	1.37400E+00	1.23700E+00	1.19400E+00	9.25100E-01	9.53500E-01
9.33400E-01	7.32900E-01	7.90000E-01	6.08300E-01	6.30000E-01	7.35100E-01	3.69600E-01	4.09200E-01
3.82700E-01	2.65600E-01	1.52700E-01	-8.56300E-02	-8.34000E-02	1.31100E-01	2.65800E-01	2.21600E-01
2.11000E-01	-3.55400E-02	-3.15800E-01	-4.82700E-01	-6.05900E-01	-7.17600E-01	-5.35500E-01	-3.43200E-01
-2.84100E-01	-2.86000E-01	-5.69200E-01	-7.53300E-01	-5.74500E-01	-6.67800E-01	-6.22600E-01	-5.07100E-01
-4.39900E-01	-4.30100E-01	-2.93800E-01	-8.40900E-02	2.83300E-02	7.02300E-02	-3.38700E-02	1.01500E-01
1.40700E-02	-1.50000E-01	-5.73100E-01	-5.13000E-01	-3.94600E-01	-1.76500E-01	-1.23700E-01	-2.67100E-02
-9.77900E-02	2.20400E-01	2.79600E-01	5.59500E-01	5.52000E-01	5.34000E-01	4.88500E-01	6.57700E-01
8.03300E-01	8.63400E-01	8.75300E-01	1.09900E+00	8.76000E-01	6.29500E-01	5.30900E-01	6.87800E-01
1.62600E-01	7.48100E-03	1.15200E-01	-2.70900E-01	-4.43700E-01	-6.21400E-01	-5.20900E-01	-4.58400E-01
-4.95300E-01	-3.72100E-01	-4.26300E-01	-3.55000E-01	-1.53400E-01	-2.13300E-01	-1.42200E-01	6.91700E-02
-2.57600E-02	-1.04200E-01	-2.38800E-01	-2.07800E-01	-7.81500E-02	-1.90000E-01	-5.21600E-01	-4.56900E-01
-1.58200E-01	1.24000E-01	1.24200E-01	-1.15300E-02	-3.75400E-01	-4.94700E-01	-5.84100E-01	-7.22500E-01
-6.84700E-01	-1.02200E+00	-1.23500E+00	-1.31300E+00	-1.43100E+00	-1.61500E+00	-1.52000E+00	-1.63400E+00
-1.54600E+00	-1.44100E+00	-1.59300E+00	-1.68600E+00	-1.65700E+00	-1.87900E+00	-2.22800E+00	-2.55400E+00
-2.74900E+00	-2.82000E+00	-3.00300E+00	-3.11000E+00	-3.31200E+00	-3.15400E+00	-3.12500E+00	-3.22200E+00
-3.12000E+00	-3.03800E+00	-2.85300E+00	-2.89300E+00	-2.76500E+00	-2.75400E+00	-2.77200E+00	-2.85400E+00
-3.01400E+00	-2.76800E+00	-2.62900E+00	-2.15300E+00	-1.83300E+00	-1.63600E+00	-1.45400E+00	-1.34500E+00
-1.15300E+00	-9.65200E-01	-1.27000E+00	-1.16800E+00	-1.14400E+00	-1.15000E+00	-1.13500E+00	-1.46600E+00
-1.67800E+00	-1.76700E+00	-1.85700E+00	-2.09800E+00	-1.95400E+00	-1.99800E+00	-2.02700E+00	-2.40300E+00
-2.00800E+00	-2.06500E+00	-2.00600E+00	-1.88700E+00	-1.54300E+00	-1.76000E+00	-1.81500E+00	-1.66600E+00
-1.52700E+00	-1.45300E+00	-1.20300E+00	-1.20300E+00	-1.27700E+00	-1.28600E+00	-1.14900E+00	-7.48900E-01
-6.31800E-01	-7.20300E-01	-5.82100E-01	-5.10900E-01	-5.18900E-01	-5.29100E-01	-5.22600E-01	-5.13300E-01
-9.58900E-02	-3.08800E-01	-3.72500E-01	-5.22300E-01	-7.09000E-01	-6.88400E-01	-6.71000E-01	-6.73900E-01
-7.05000E-01	-6.06100E-01	-7.07000E-01	-6.24500E-01	-3.34100E-01	-2.96000E-01	-3.64600E-01	-2.77700E-01
1.16900E-02	3.12100E-01	3.57800E-01	3.76500E-01	2.16300E-01	2.98900E-01	3.99300E-01	1.50400E-01
3.10200E-01	3.19200E-01	4.17700E-01	2.21000E-01	2.35900E-02	-6.09000E-02	-1.55500E-01	-3.46100E-01
-2.95400E-01	-3.54600E-01	-2.60300E-01	-2.25700E-01	-6.13700E-01	-6.88000E-01	-8.58300E-01	-7.55600E-01
-5.80300E-01	-3.93900E-01	-3.97700E-01	-4.38400E-01	-5.14100E-01	-4.87300E-01	-5.49100E-01	-7.11300E-01
-8.80400E-01	-8.36500E-01	-6.92800E-01	-9.77600E-01	-1.03800E+00	-1.07700E+00	-7.32700E-01	-6.63900E-01
-5.83600E-01	-8.74900E-01	-1.12400E+00	-1.15400E+00	-1.06600E+00	-9.75900E-01	-6.21200E-01	-3.30800E-01

-4.73400E-01	-4.46600E-01	-2.64300E-01	-5.80800E-01	-6.84600E-01	-7.91100E-01	-1.08700E+00	-1.19000E+00
-1.22100E+00	-8.35600E-01	-7.80200E-01	-1.01400E+00	-1.08400E+00	-8.44800E-01	-9.70600E-01	-1.01200E+00
-7.98600E-01	-8.16400E-01	-9.49100E-01	-9.38500E-01	-1.24200E+00	-1.11600E+00	-1.24200E+00	-1.18400E+00
-1.30700E+00	-1.31000E+00	-1.40800E+00	-1.26900E+00	-1.17000E+00	-1.11400E+00	-1.56300E+00	-1.59000E+00
-1.71000E+00	-1.73900E+00	-1.54300E+00	-1.41500E+00	-1.30800E+00	-1.12800E+00	-1.02400E+00	-8.30800E-01
-8.17700E-01	-8.03300E-01	-8.19500E-01	-9.18000E-01	-6.65100E-01	-6.23400E-01	-7.44200E-01	-6.63600E-01
-4.60800E-01	-2.04500E-01	-1.32100E-01	-9.29000E-02	-2.28500E-01	-2.65800E-01	-2.42300E-01	-4.18700E-01
-3.88400E-01	-1.72600E-01	4.17900E-02	9.38400E-02	1.22500E-03	5.90800E-02	8.88000E-02	1.87600E-01
-8.47200E-03	5.56400E-02	1.12500E-02	1.01000E-02	-4.12200E-02	-2.45000E-02	1.04400E-01	-7.04900E-03
-1.23600E-01	-2.66500E-03	1.21300E-01	4.45100E-01	3.69600E-01	2.18600E-01	5.42200E-01	8.82400E-01
1.01300E+00	1.18600E+00	1.38600E+00	1.31700E+00	1.56700E+00	1.60500E+00	1.44800E+00	1.54900E+00
1.46600E+00	1.54000E+00	1.57400E+00	1.51900E+00	1.58900E+00	1.62000E+00	1.40100E+00	1.55100E+00
1.17400E+00	8.18700E-01	6.89200E-01	8.87700E-01	8.48900E-01	8.82000E-01	1.16600E+00	1.20100E+00
7.04200E-01	5.65400E-01	4.73700E-01	4.87800E-01	5.65900E-01	4.16600E-01	3.81300E-01	2.24000E-01
2.79500E-01	4.19600E-01	4.63000E-01	4.67900E-01	3.17300E-01	4.89300E-01	5.68300E-01	3.78200E-01
2.07800E-01	2.59900E-01	4.21100E-01	2.97400E-01	4.36600E-01	4.51800E-01	6.00100E-01	6.91100E-01
9.81700E-01	9.84600E-01	1.14300E+00	1.11900E+00	1.10000E+00	9.76200E-01	1.30900E+00	1.19400E+00
1.41700E+00	1.36800E+00	1.43500E+00	1.42300E+00	1.52200E+00	1.63400E+00	1.48700E+00	1.48200E+00
1.59600E+00	1.82500E+00	1.80500E+00	1.80700E+00	1.66500E+00	1.71900E+00	1.83200E+00	1.92000E+00
2.02000E+00	2.19700E+00	2.23200E+00	2.49900E+00	2.68600E+00	2.49800E+00	2.64200E+00	2.30300E+00
2.06700E+00	2.13200E+00	2.12500E+00	2.05700E+00	2.12900E+00	1.77500E+00	1.67900E+00	1.50700E+00
1.32200E+00	1.40200E+00	1.61700E+00	1.92900E+00	1.64900E+00	1.31300E+00	1.18800E+00	1.41300E+00
1.71200E+00	1.54500E+00	1.65300E+00	1.66500E+00	1.48000E+00	1.35200E+00	1.33700E+00	1.14700E+00
1.07300E+00	1.02200E+00	1.08300E+00	1.03300E+00	1.32800E+00	1.22700E+00	1.02500E+00	9.58100E-01
1.24500E+00	1.26300E+00	1.20100E+00	1.45300E+00	1.48700E+00	1.42300E+00	1.18800E+00	1.13200E+00
1.09100E+00	9.67600E-01	9.24600E-01	6.96400E-01	6.47100E-01	5.31200E-01	6.22100E-01	8.01300E-01
1.00500E+00	8.54400E-01	1.20600E+00	1.45100E+00	1.52100E+00	1.28600E+00	1.46000E+00	1.45400E+00
1.59900E+00	1.55100E+00	1.41900E+00	1.25100E+00	1.13300E+00	1.30700E+00	1.35400E+00	1.47000E+00
1.53200E+00	1.52100E+00	1.40700E+00	1.57600E+00	1.19000E+00	1.22900E+00	1.18700E+00	1.03100E+00
1.02500E+00	9.83400E-01	1.11100E+00	1.42500E+00	1.16600E+00	1.22500E+00	1.26000E+00	1.24400E+00
1.13200E+00	1.13800E+00	1.09300E+00	1.08800E+00	1.30100E+00	1.24700E+00	9.90800E-01	9.85600E-01
8.05800E-01	1.00100E+00	1.12800E+00	1.20600E+00	1.30700E+00	1.51600E+00	1.59200E+00	1.48100E+00
1.31400E+00	9.75900E-01	8.88700E-01	7.73800E-01	8.51800E-01	1.00400E+00	1.08900E+00	1.12100E+00
1.18400E+00	1.30900E+00	1.44600E+00	1.53800E+00	1.70800E+00	1.53700E+00	1.28200E+00	1.44300E+00
1.56900E+00	1.45000E+00	1.25100E+00	1.33000E+00	1.10500E+00	8.88500E-01	7.83400E-01	9.16600E-01
8.96200E-01	1.09500E+00	1.34000E+00	1.47700E+00	1.50900E+00	1.55100E+00	1.26900E+00	1.26500E+00
1.33600E+00	1.07200E+00	6.22400E-01	3.36500E-01	2.75400E-01	5.47800E-01	3.53600E-01	2.07300E-01
1.66700E-01	1.72400E-01	1.69100E-01	-1.34900E-01	-2.15400E-02	1.67900E-01	-1.66300E-01	-1.11700E-01
-2.86100E-01	-4.93500E-01	-6.50600E-01	-6.82400E-01	-6.70600E-01	-6.54200E-01	-7.31200E-01	-8.06400E-01
-9.18400E-01	-9.81300E-01	-1.27600E+00	-1.21900E+00	-1.52800E+00	-1.44400E+00	-1.38900E+00	-1.36900E+00
-1.51500E+00	-1.60300E+00	-1.95300E+00	-1.91800E+00	-1.74300E+00	-2.10200E+00	-2.45200E+00	-2.52000E+00
-2.55100E+00	-2.46400E+00	-2.28400E+00	-2.24600E+00	-2.10800E+00	-2.06700E+00	-1.78000E+00	-1.61200E+00
-1.42600E+00	-1.44400E+00	-1.47500E+00	-1.66400E+00	-1.75600E+00	-1.75900E+00	-1.44400E+00	-1.10500E+00
-1.03500E+00	-1.13900E+00	-1.14100E+00	-1.11800E+00	-1.00600E+00	-1.16900E+00	-1.34800E+00	-1.50100E+00
-1.52100E+00	-1.52500E+00	-1.22000E+00	-1.11200E+00	-9.56600E-01	-9.16900E-01	-8.94200E-01	-9.57100E-01
-1.21900E+00	-9.54800E-01	-7.99500E-01	-9.34600E-01	-6.81400E-01	-5.10200E-01	-6.52100E-01	-6.80200E-01
-8.87900E-01	-7.40500E-01	-9.85500E-01	-7.81300E-01	-8.06400E-01	-1.07500E+00	-1.23200E+00	-1.34700E+00
-1.32700E+00	-1.43800E+00	-1.46100E+00	-1.55800E+00	-1.24700E+00	-1.18400E+00	-1.26500E+00	-1.43900E+00
-1.43300E+00	-1.56600E+00	-1.33400E+00	-1.32100E+00	-1.30700E+00	-1.32000E+00	-1.51900E+00	-2.00400E+00
-2.22200E+00	-2.32500E+00	-2.40800E+00	-2.36500E+00	-2.40700E+00	-2.11700E+00	-2.03300E+00	-2.38900E+00
-2.37000E+00	-2.15300E+00	-2.15900E+00	-2.17000E+00	-1.93900E+00	-2.03600E+00	-1.90700E+00	-2.03100E+00
-1.97200E+00	-1.81600E+00	-1.47700E+00	-1.62200E+00	-1.76700E+00	-1.81400E+00	-1.58300E+00	-1.66700E+00
-1.74300E+00	-1.76200E+00	-1.75800E+00	-1.65200E+00	-1.35500E+00	-1.37700E+00	-1.43300E+00	-1.40000E+00
-1.34800E+00	-1.19500E+00	-1.35300E+00	-1.45100E+00	-1.36000E+00	-1.51300E+00	-1.26000E+00	-1.42500E+00
-1.15600E+00	-1.18100E+00	-1.27000E+00	-1.19900E+00	-1.19800E+00	-1.24300E+00	-1.31300E+00	-1.36800E+00
-1.26500E+00	-1.18300E+00	-1.38300E+00	-1.54500E+00	-1.65300E+00	-1.48800E+00	-1.56200E+00	-1.32400E+00
-1.36900E+00	-1.38900E+00	-1.44900E+00	-1.09100E+00	-1.15400E+00	-1.29000E+00	-1.20800E+00	-1.06900E+00
-1.20400E+00	-1.30300E+00	-1.16700E+00	-1.13400E+00	-7.72700E-01	-5.16400E-01	-4.75500E-01	-6.72100E-01
-8.07600E-01	-8.83900E-01	-6.39200E-01	-7.16700E-01	-7.55300E-01	-6.14100E-01	-6.49000E-01	-7.72600E-01
-2.32600E-01	-2.23800E-01	-3.18100E-01	-1.85000E-01	2.06600E-02	-9.23700E-02	2.32100E-03	-8.73400E-02
-1.55900E-01	-1.00700E-01	-1.58500E-01	-2.30400E-01	-8.27500E-01	-8.02300E-01	-8.00500E-01	-9.18800E-01

-7.43700E-01	-5.11300E-01	-4.62200E-01	-5.23400E-01	-7.22100E-01	-4.69600E-01	-3.44800E-01	-4.59500E-02
-1.70400E-01	-2.87400E-01	-1.07700E-01	1.15300E-01	1.29500E-01	2.15900E-01	2.51500E-01	1.24400E-01
-1.20300E-01	-1.33500E-01	-2.55000E-02	6.85600E-02	2.33300E-02	8.34500E-02	1.62300E-01	2.27800E-01
-3.35900E-03	-3.43000E-02	-9.32700E-03	1.04100E-01	6.23700E-02	1.27800E-01	1.35600E-01	4.11200E-01
5.59500E-01	6.79700E-01	4.88700E-01	4.36100E-01	2.31900E-01	2.05700E-01	1.91400E-01	2.16000E-01
2.04400E-01	4.23300E-01	2.94600E-01	-8.28800E-02	4.01800E-03	2.61500E-01	1.55400E-01	2.22700E-01
2.31600E-01	3.68700E-01	5.10200E-01	4.61900E-01	4.92300E-01	4.44800E-01	3.27500E-01	2.81600E-01
5.39100E-01	1.24200E-01	2.16400E-01	3.07300E-01	2.62400E-01	4.10300E-01	3.34600E-01	2.68100E-01
1.66400E-01	-3.98800E-02	1.64100E-02	-1.26600E-02	-1.06900E-01	-3.02800E-01	-4.27100E-01	-1.54600E-01
-2.32300E-01	-2.31900E-01	-3.20000E-01	-4.49900E-01	-5.33500E-01	-3.96800E-01	-4.51200E-01	-6.93800E-01
-8.96500E-01	-7.91100E-01	-7.92900E-01	-6.23600E-01	-3.67300E-01	-1.48900E-01	1.43300E-01	5.32400E-01
4.45600E-01	2.81900E-01	3.84100E-01	7.78800E-01	9.13100E-01	1.08800E+00	1.23600E+00	1.20600E+00
1.05800E+00	1.05700E+00	1.01400E+00	1.04600E+00	1.15400E+00	1.23800E+00	1.28100E+00	1.19200E+00
9.64000E-01	5.57400E-01	5.45000E-01	4.26800E-01	6.56900E-01	5.81900E-01	8.96000E-01	9.06800E-01
9.55600E-01	8.61300E-01	9.55900E-01	1.23400E+00	1.24500E+00	1.19600E+00	1.33700E+00	1.55700E+00
1.41900E+00	1.23400E+00	1.07400E+00	9.62500E-01	1.21100E+00	1.00800E+00	7.23200E-01	8.58100E-01
6.85600E-01	7.13400E-01	1.07600E+00	1.10900E+00	1.40400E+00	1.15000E+00	1.16100E+00	1.15100E+00
1.17900E+00	1.01300E+00	1.08100E+00	8.96500E-01	8.01000E-01	9.32700E-01	1.45800E+00	1.71600E+00
2.10100E+00	2.44100E+00	2.38700E+00	2.24400E+00	2.22500E+00	2.35100E+00	2.22300E+00	1.96200E+00
1.87800E+00	2.06200E+00	2.22500E+00	2.23000E+00	2.08800E+00	2.08200E+00	2.17500E+00	2.05900E+00
2.11300E+00	1.90100E+00	1.73000E+00	1.63700E+00	1.73300E+00	1.62500E+00	1.59700E+00	1.86800E+00
1.75600E+00	1.64200E+00	1.44100E+00	1.61400E+00	1.54700E+00	1.63200E+00	1.63500E+00	1.39900E+00
1.38000E+00	1.44500E+00	1.39200E+00	1.33600E+00	1.52000E+00	1.43400E+00	1.29300E+00	1.21600E+00
1.33800E+00	1.24600E+00	1.45500E+00	1.48500E+00	1.68800E+00	1.36800E+00	1.50700E+00	1.39100E+00
1.48600E+00	1.51200E+00	1.37100E+00	1.39200E+00	1.26600E+00	1.13900E+00	1.53500E+00	1.68400E+00
1.72500E+00	1.77500E+00	1.47400E+00	1.75500E+00	2.01000E+00	2.02000E+00	1.99600E+00	2.18300E+00
2.24900E+00	2.21500E+00	2.02700E+00	1.64000E+00	1.37200E+00	1.15500E+00	8.21500E-01	5.94100E-01
4.88900E-01	3.52700E-01	4.59200E-01	7.29200E-01	7.85700E-01	9.26100E-01	6.70300E-01	8.05700E-01
9.37000E-01	1.07400E+00	8.92500E-01	8.95000E-01	9.96700E-01	8.15600E-01	4.99900E-01	4.15800E-01
4.57000E-01	2.81800E-01	1.09500E-01	2.48600E-01	1.41200E-01	1.74000E-01	1.55200E-01	1.29100E-01
1.10400E-01	1.41400E-02	-1.20900E-01	-2.86400E-01	-4.08300E-01	-3.11600E-01	-2.06500E-01	-1.49200E-01
-4.46700E-01	-4.94100E-01	-4.97100E-01	-3.80200E-01	-6.42100E-01	-5.62100E-01	-4.10300E-01	-4.38900E-01
-1.95700E-01	2.14800E-01	2.27800E-01	2.98700E-01	2.53300E-01	3.82900E-01	4.57400E-01	5.08300E-01
6.78200E-01	4.96600E-01	7.86000E-01	9.77400E-01	8.05800E-01	7.85400E-01	8.45900E-01	9.27500E-01
1.17900E+00	1.25800E+00	1.29100E+00	1.30000E+00	1.15800E+00	1.11400E+00	9.35300E-01	7.01700E-01
7.72000E-01	7.74700E-01	4.02400E-01	1.59400E-01	4.20300E-01	5.45700E-01	5.22500E-01	5.67100E-01
1.76600E-01	3.29700E-01	2.18700E-01	2.49500E-01	1.81600E-01	3.84900E-01	3.67500E-01	6.28100E-01
7.81800E-01	7.34500E-01	4.66000E-01	2.48600E-01	5.09200E-02	1.44100E-01	1.23000E-01	3.24800E-01
2.57300E-01	1.13900E-02	-2.74600E-01	-4.64400E-01	-3.44800E-01	-2.20300E-01	-2.36600E-01	-2.66900E-01
-3.53500E-01	-6.10500E-01	-7.85800E-01	-8.69600E-01	-9.26200E-01	-7.79700E-01	-7.85000E-01	-1.03200E+00
-9.74400E-01	-9.99600E-01	-1.06500E+00	-1.39100E+00	-1.37000E+00	-1.03700E+00	-1.08100E+00	-1.11900E+00
-1.04200E+00	-1.21100E+00	-1.17400E+00	-1.45000E+00	-1.43600E+00	-1.50200E+00	-1.55600E+00	-1.58700E+00
-1.45200E+00	-1.51200E+00	-1.72300E+00	-1.94600E+00	-1.91400E+00	-2.04700E+00	-2.51500E+00	-2.52700E+00
-2.78100E+00	-2.76500E+00	-2.62600E+00	-2.75400E+00	-3.16200E+00	-3.49500E+00	-3.38800E+00	-3.50500E+00
-3.33700E+00	-3.36800E+00	-3.26300E+00	-3.24500E+00	-3.25900E+00	-3.18300E+00	-2.90400E+00	-2.90900E+00
-2.70400E+00	-2.77800E+00	-2.84100E+00	-2.73000E+00	-2.58400E+00	-2.78700E+00	-2.65800E+00	-2.33800E+00
-2.53800E+00	-2.46600E+00	-2.38700E+00	-2.27700E+00	-2.17900E+00	-2.04900E+00	-2.09800E+00	-2.15400E+00
-2.24400E+00	-2.11700E+00	-1.98500E+00	-1.95100E+00	-1.97500E+00	-2.09600E+00	-2.16300E+00	-2.17900E+00
-2.15400E+00	-2.22000E+00	-2.03800E+00	-2.31400E+00	-2.05100E+00	-1.92000E+00	-1.96900E+00	-2.03600E+00
-2.03200E+00	-1.68600E+00	-1.53500E+00	-1.74900E+00	-1.87700E+00	-1.83700E+00	-1.63500E+00	-1.62900E+00
-1.75200E+00	-1.83300E+00	-1.70600E+00	-1.78800E+00	-1.29100E+00	-1.25100E+00	-9.03400E-01	-8.66100E-01
-6.92000E-01	-8.14000E-01	-8.34400E-01	-7.65500E-01	-7.63800E-01	-8.95800E-01	-8.09800E-01	-8.88200E-01
-7.35200E-01	-5.19500E-01	-4.40100E-01	-5.53600E-01	-7.39200E-01	-6.62400E-01	-8.25400E-01	-8.32700E-01
-1.19300E+00	-1.12300E+00	-9.17400E-01	-8.91900E-01	-9.63300E-01	-6.76100E-01	-6.14600E-01	-7.37400E-01
-6.48800E-01	-4.30300E-01	-3.68400E-01	-4.55200E-01	-5.75900E-01	-5.13600E-01	-2.32400E-01	-2.79300E-01
-1.05000E-01	-2.18800E-01	-4.31600E-01	-3.05900E-01	-2.97900E-01	-4.38800E-01	-4.12300E-01	-2.33600E-01
-4.83500E-01	-1.82900E-01	8.78800E-03	2.15800E-01	4.40100E-01	5.09000E-01	5.41300E-01	3.35100E-01
3.46200E-01	4.55100E-01	3.57800E-01	4.27000E-01	5.72700E-01	4.50400E-01	6.04000E-01	8.42000E-01
7.08100E-01	4.94500E-01	9.75200E-02	6.43200E-02	-2.72700E-02	-1.97900E-01	-2.58300E-01	-2.33100E-01
6.56300E-02	2.16300E-01	2.87700E-01	5.55500E-01	5.33400E-01	5.33600E-01	4.10700E-01	4.49300E-01
4.96500E-01	5.69500E-01	8.45400E-01	8.48200E-01	7.60200E-01	5.86900E-01	5.28900E-01	6.38400E-01

8.54100E-01	1.09200E+00	1.33700E+00	1.33600E+00	1.13100E+00	1.02700E+00	1.19200E+00	1.11400E+00
8.77700E-01	9.75600E-01	8.86000E-01	9.67900E-01	8.61200E-01	1.09000E+00	1.01800E+00	1.16600E+00
9.73900E-01	9.30400E-01	8.01500E-01	4.34700E-01	-6.53000E-02	-1.76900E-01	-2.54300E-01	-5.46100E-02
-3.38700E-02	-1.75900E-01	-4.10700E-01	-1.01400E-01	-3.36800E-01	-2.64300E-01	-1.60600E-01	8.82300E-02
4.02500E-01	3.07700E-01	-2.75000E-02	-9.70900E-02	-2.07800E-01	-1.40400E-01	3.64300E-01	3.35600E-01
3.30100E-01	5.04400E-01	8.81500E-01	1.02700E+00	8.18700E-01	8.97300E-01	9.00400E-01	7.75800E-01
9.17300E-01	8.29600E-01	8.18500E-01	7.80400E-01	6.27900E-01	3.14800E-01	1.83800E-01	3.72500E-01
2.46300E-01	1.85700E-01	3.95600E-01	4.36800E-01	4.21600E-01	3.50000E-01	3.89700E-01	5.32300E-01
7.34500E-01	1.04500E+00	1.07700E+00	1.12200E+00	1.17200E+00	1.19700E+00	1.30700E+00	1.42100E+00
1.60500E+00	1.56500E+00	1.55700E+00	1.52300E+00	1.67900E+00	1.97400E+00	1.78100E+00	1.69500E+00
1.65200E+00	1.79500E+00	1.82900E+00	2.00700E+00	2.08100E+00	1.98800E+00	1.96400E+00	1.91700E+00
2.27000E+00	2.37100E+00	2.52500E+00	2.59900E+00	2.96100E+00	2.96600E+00	2.73900E+00	2.66600E+00
2.46100E+00	2.23700E+00	2.14300E+00	2.03200E+00	1.87700E+00	1.99900E+00	1.79800E+00	1.93700E+00
1.95600E+00	1.69400E+00	1.83300E+00	1.86100E+00	1.53400E+00	1.54400E+00	1.53600E+00	1.63100E+00
1.60100E+00	1.30300E+00	1.28300E+00	1.09000E+00	1.16600E+00	9.97600E-01	1.10100E+00	9.16900E-01
7.51000E-01	5.37400E-01	5.84700E-01	4.78100E-01	6.53100E-01	4.11900E-01	4.01200E-01	2.32700E-01
4.67700E-01	4.06100E-01	2.79300E-01	5.58400E-01	6.53600E-01	5.30800E-01	5.71900E-01	8.72700E-01
9.32700E-01	8.10700E-01	9.42200E-01	7.75600E-01	8.50100E-01	7.36400E-01	8.28800E-01	6.72300E-01
7.97800E-01	8.02600E-01	6.23800E-01	4.98500E-01	5.85800E-01	6.87100E-01	6.08600E-01	8.18900E-01
7.03800E-01	8.33300E-01	1.06500E+00	1.20500E+00	9.58500E-01	6.68600E-01	4.54500E-01	6.26400E-01
6.03700E-01	3.43200E-01	8.01200E-02	6.01400E-02	1.49300E-01	8.59000E-02	5.24500E-02	2.52800E-02
2.87100E-02	-1.14400E-02	-5.13100E-02	-4.16500E-01	-2.51100E-01	-4.33100E-01	-4.25500E-01	-5.60200E-01
-9.98600E-01	-1.08400E+00	-1.09800E+00	-1.35000E+00	-1.15200E+00	-1.00500E+00	-1.12300E+00	-1.17800E+00
-1.20300E+00	-8.74300E-01	-7.84900E-01	-6.77000E-01	-8.38600E-01	-6.21300E-01	-5.11300E-01	-7.06100E-01
-5.48000E-01	-6.67200E-01	-6.75600E-01	-8.45400E-01	-7.08200E-01	-6.97700E-01	-8.37200E-01	-9.48400E-01
-8.79400E-01	-6.85900E-01	-5.13300E-01	-2.26300E-01	-1.98800E-01	-3.59000E-01	-6.55600E-01	-8.36600E-01
-7.73800E-01	-7.64600E-01	-8.17800E-01	-7.98200E-01	-8.99700E-01	-1.20100E+00	-1.23600E+00	-1.20300E+00
-1.35000E+00	-1.22400E+00	-1.11100E+00	-1.02200E+00	-1.09900E+00	-1.22300E+00	-1.35000E+00	-1.32500E+00
-9.79000E-01	-6.46000E-01	-9.18800E-01	-1.00900E+00	-9.75600E-01	-1.17400E+00	-1.47400E+00	-1.37000E+00
-1.63600E+00	-1.63100E+00	-1.77600E+00	-1.47100E+00	-1.28800E+00	-9.35700E-01	-8.35200E-01	-7.33300E-01
-7.67200E-01	-5.15700E-01	-7.19700E-01	-5.99700E-01	-6.27000E-01	-6.87700E-01	-5.55600E-01	-7.47100E-01
-4.39200E-01	-2.89000E-01	-5.02500E-01	-7.42800E-01	-1.05900E+00	-1.29600E+00	-1.48500E+00	-1.39200E+00
-1.30600E+00	-9.92400E-01	-7.07100E-01	-8.12100E-01	-6.40700E-01	-7.60000E-01	-9.33600E-01	-9.31700E-01
-8.12000E-01	-8.95400E-01	-7.27900E-01	-5.19300E-01	-5.23900E-01	-5.34900E-01	-6.19200E-01	-4.49400E-01
-4.02500E-01	-3.61100E-01	-4.96300E-01	-3.91800E-01	-2.31100E-01	-5.29100E-03	-4.05900E-02	-2.03300E-01
-2.63400E-01	-1.27200E-01	1.12300E-01	3.20000E-01	2.00200E-01	5.18200E-01	8.63000E-01	8.35100E-01
7.23300E-01	9.18900E-01	1.24500E+00	1.57400E+00	1.49800E+00	1.51500E+00	1.63100E+00	1.59700E+00
1.63400E+00	1.74400E+00	1.67300E+00	1.52500E+00	1.37300E+00	1.50700E+00	1.66300E+00	1.49700E+00
1.51600E+00	1.49400E+00	1.21500E+00	1.44500E+00	1.37800E+00	1.32500E+00	1.12500E+00	1.05400E+00
9.69100E-01	5.80600E-01	6.73000E-01	4.18100E-01	4.05100E-01	6.28300E-01	6.86700E-01	6.21700E-01
6.11000E-01	7.16400E-01	5.38700E-01	4.26400E-01	2.36600E-01	1.95600E-01	1.82900E-02	-1.18400E-01
-5.98700E-02	-1.10600E-01	-4.06600E-01	-5.41100E-01	-3.03100E-01	-3.73200E-01	-1.34300E-01	-2.99900E-01
-4.51400E-01	-6.07200E-01	-6.10100E-01	-9.61000E-01	-9.28200E-01	-1.14800E+00	-1.35700E+00	-1.59800E+00
-1.42200E+00	-1.35300E+00	-1.01200E+00	-1.14500E+00	-1.38700E+00	-1.46800E+00	-1.44600E+00	-1.50500E+00
-1.62700E+00	-1.69200E+00	-1.72900E+00	-1.92300E+00	-2.04700E+00	-1.87600E+00	-2.12500E+00	-2.19100E+00
-2.22000E+00	-2.19100E+00	-2.15700E+00	-2.23600E+00	-2.49300E+00	-2.55900E+00	-2.51900E+00	-2.59600E+00
-2.28600E+00	-2.37100E+00	-2.12300E+00	-2.01300E+00	-1.81200E+00	-1.44400E+00	-1.47200E+00	-1.09000E+00
-1.00800E+00	-9.70600E-01	-1.02800E+00	-1.06400E+00	-1.12100E+00	-1.33000E+00	-1.36700E+00	-1.38300E+00
-1.29100E+00	-1.35400E+00	-1.31200E+00	-1.34900E+00	-1.17700E+00	-1.27800E+00	-9.45200E-01	-1.00100E+00
-1.36200E+00	-1.64700E+00	-1.32700E+00	-1.26800E+00	-1.21300E+00	-9.99200E-01	-6.63100E-01	-6.67200E-01
-6.97400E-01	-8.95100E-01	-7.71700E-01	-3.70300E-01	-2.76800E-01	-3.95300E-01	-6.99000E-01	-7.39500E-01
-6.51500E-01	-6.19000E-01	-7.29600E-01	-6.38500E-01	-6.76900E-01	-8.27800E-01	-7.50100E-01	-8.32400E-01
-1.08200E+00	-1.01400E+00	-7.10400E-01	-9.86000E-01	-8.03200E-01	-9.23400E-01	-9.07500E-01	-1.02100E+00
-1.01200E+00	-9.26300E-01	-8.10700E-01	-6.46400E-01	-5.21100E-01	-1.58400E-01	-2.13500E-01	-8.21800E-02
-2.46100E-01	5.16000E-02	4.03900E-01	3.57500E-01	6.33000E-01	7.46900E-01	6.87100E-01	7.67600E-01
5.35200E-01	4.78900E-01	4.67200E-01	7.15900E-01	8.19900E-01	8.77600E-01	8.87200E-01	8.92400E-01
7.46300E-01	9.79700E-01	1.18600E+00	1.32100E+00	1.11600E+00	1.08200E+00	1.10600E+00	1.20000E+00
1.22500E+00	1.27200E+00	1.33300E+00	1.56300E+00	1.45400E+00	1.59600E+00	1.78300E+00	1.92000E+00
1.98800E+00	2.07300E+00	2.12100E+00	2.02100E+00	2.02100E+00	1.87800E+00	1.95600E+00	1.89000E+00
1.84200E+00	1.74600E+00	1.89900E+00	1.76900E+00	1.99500E+00	2.02600E+00	1.71800E+00	1.56500E+00
1.51100E+00	1.62100E+00	1.48300E+00	1.76600E+00	1.65800E+00	1.47100E+00	1.34100E+00	1.36100E+00

1.54100E+00	1.49100E+00	1.37100E+00	1.60000E+00	1.74100E+00	1.80800E+00	1.91300E+00	1.93900E+00
1.43000E+00	1.63800E+00	1.53400E+00	1.70500E+00	1.80500E+00	1.61000E+00	1.39000E+00	1.27000E+00
1.18500E+00	1.02000E+00	6.88400E-01	8.72800E-01	9.63300E-01	8.54200E-01	1.13300E+00	1.54600E+00
1.65400E+00	1.52000E+00	1.18200E+00	1.07500E+00	9.99100E-01	1.02500E+00	8.72100E-01	1.00400E+00
1.20500E+00	1.26500E+00	1.26000E+00	1.05700E+00	7.91700E-01	7.90000E-01	8.64600E-01	8.00100E-01
5.01200E-01	5.43000E-01	8.19000E-01	9.25600E-01	8.97900E-01	1.08700E+00	1.09900E+00	1.19000E+00
1.14600E+00	1.01600E+00	9.24700E-01	9.71400E-01	1.07900E+00	9.48200E-01	1.14200E+00	9.38900E-01
9.73900E-01	8.91400E-01	7.15200E-01	6.34000E-01	2.77600E-01	4.11900E-02	-3.57400E-02	1.25200E-01
1.49100E-01	9.36500E-02	2.61400E-01	3.63900E-01	6.70100E-01	4.97300E-01	3.89600E-01	1.44500E-01
2.43200E-01	-2.09700E-02	5.17400E-02	2.18700E-01	-6.25500E-02	-3.08800E-01	-3.83300E-01	-5.87500E-01
-4.72400E-01	-3.69000E-01	-3.22900E-01	-5.05200E-02	-3.08100E-01	-2.82900E-01	-2.66500E-01	-2.27200E-01
-6.07000E-02	1.64300E-01	5.92100E-02	-5.44600E-02	-2.48900E-02	2.15100E-01	1.08300E-01	1.22100E-01
1.53500E-01	5.39900E-02	-9.40200E-02	-6.49100E-02	7.17000E-02	-9.30300E-02	-8.32300E-03	-1.18500E-01
-2.27600E-01	-4.28500E-01	-5.08300E-01	-9.91700E-01	-8.90400E-01	-9.05700E-01	-9.45800E-01	-1.13300E+00
-1.21300E+00	-1.16100E+00	-1.32000E+00	-1.15700E+00	-1.00900E+00	-9.06300E-01	-9.38300E-01	-1.05600E+00
-8.47600E-01	-1.05300E+00	-9.35100E-01	-1.20500E+00	-9.30300E-01	-8.25800E-01	-8.42300E-01	-7.89100E-01
-4.92200E-01	-6.81700E-01	-7.75500E-01	-6.12200E-01	-5.01300E-01	-4.86700E-01	-5.19900E-01	-5.38800E-01
-4.84000E-01	-6.04700E-01	-8.14300E-01	-9.42200E-01	-9.80800E-01	-6.94300E-01	-5.07600E-01	-5.43900E-01
-8.22400E-01	-1.03800E+00	-8.05100E-01	-7.27500E-01	-4.75500E-01	-2.05700E-01	-2.00200E-01	-5.02900E-02
-1.31200E-02	-2.39700E-01	2.05000E-01	3.00300E-01	2.64900E-01	4.81800E-02	1.95500E-02	3.73400E-02
2.07600E-01	1.53900E-01	-7.48900E-02	9.46700E-02	3.74900E-01	7.65800E-01	6.59400E-01	7.48200E-01
6.25200E-01	8.34300E-01	6.28700E-01	7.72000E-01	8.22700E-01	7.21400E-01	7.20600E-01	5.81800E-01
6.80200E-01	3.21600E-01	9.04000E-02	1.00300E-01	9.21000E-03	-6.73800E-02	-1.03700E-01	-1.45700E-02
-6.51500E-02	1.46400E-01	2.76800E-01	8.56400E-02	2.75300E-01	5.62200E-01	7.50200E-01	7.77700E-01
7.68900E-01	7.12800E-01	6.03700E-01	4.62600E-01	4.59100E-01	1.94100E-01	-1.46400E-02	-7.45900E-02
-2.12300E-01	-1.96500E-01	8.63200E-02	4.81800E-02	2.24000E-01	4.44100E-01	3.82300E-01	2.30200E-01
1.34100E-02	-1.51300E-01	-1.72500E-02	-8.77200E-02	-1.42000E-01	-1.01900E-01	-8.75600E-02	4.38200E-02
-3.64500E-02	5.86100E-01	6.75400E-01	8.47600E-01	8.47000E-01	1.12000E+00	1.09300E+00	1.06200E+00
7.97000E-01	9.16300E-01	6.95200E-01	3.77800E-01	5.51600E-01	6.31800E-01	6.07400E-01	6.78200E-01
6.78600E-01	5.54400E-01	3.60000E-01	3.98800E-01	1.05100E-01	2.51500E-01	7.09400E-02	-3.32700E-02
1.29100E-01	1.77900E-01	1.56900E-01	-1.10600E-01	-2.48000E-01	-3.42900E-01	-3.79600E-01	-2.17000E-01
-2.68700E-01	-4.03000E-01	-7.03800E-01	-8.57700E-01	-1.11500E+00	-1.17100E+00	-1.07300E+00	-9.61400E-01
-9.91500E-01	-8.44000E-01	-7.56200E-01	-4.77200E-01	-4.18200E-01	-5.18000E-01	-4.10300E-01	-4.27300E-01
-4.56100E-01	-4.13400E-01	-5.18300E-01	-4.75200E-01	-1.45200E-01	-1.61300E-01	-5.84300E-01	-9.38000E-01
-1.03600E+00	-8.54600E-01	-1.06900E+00	-1.15100E+00	-1.01700E+00	-1.31100E+00	-1.27000E+00	-1.50900E+00
-1.71300E+00	-1.69300E+00	-1.53700E+00	-1.63300E+00	-1.67600E+00	-1.53000E+00	-1.49700E+00	-1.53800E+00
-1.67300E+00	-1.59800E+00	-1.68700E+00	-1.55400E+00	-1.72700E+00	-1.80500E+00	-1.73600E+00	-1.80200E+00
-1.47400E+00	-1.39200E+00	-1.40100E+00	-1.48500E+00	-1.56600E+00	-1.42000E+00	-1.38400E+00	-1.25300E+00
-1.70400E+00	-1.72600E+00	-1.71300E+00	-1.51200E+00	-1.44900E+00	-1.72600E+00	-2.09100E+00	-2.10100E+00
-2.38700E+00	-2.58000E+00	-2.42500E+00	-2.39000E+00	-2.49300E+00	-2.39300E+00	-1.94200E+00	-2.01600E+00
-1.97500E+00	-2.05500E+00	-2.09100E+00	-2.44000E+00	-2.68600E+00	-2.73800E+00	-2.41500E+00	-2.25900E+00
-1.97800E+00	-2.12700E+00	-2.03300E+00	-2.18300E+00	-2.28700E+00	-2.30800E+00	-2.05800E+00	-2.26300E+00
-2.23200E+00	-2.10000E+00	-2.14200E+00	-1.96800E+00	-2.06400E+00	-1.83700E+00	-1.61500E+00	-1.55800E+00
-1.34600E+00	-1.41700E+00	-1.50200E+00	-1.55500E+00	-1.28600E+00	-1.15500E+00	-7.38800E-01	-7.79100E-01
-5.33800E-01	-6.24200E-01	-7.09900E-01	-6.20500E-01	-7.77600E-01	-7.61000E-01	-7.19100E-01	-4.74400E-01
-5.93100E-01	-5.64200E-01	-3.83100E-01	-5.00600E-01	-3.42700E-01	-1.80400E-01	-1.87900E-01	-1.74400E-01
-5.55200E-02	-6.28800E-02	-1.07400E-01	-1.21500E-01	4.71600E-02	5.93700E-02	1.93900E-01	1.65700E-01
4.39300E-01	5.68400E-01	4.70100E-01	4.21900E-01	2.86300E-01	2.58400E-01	4.68200E-01	4.64600E-01
4.49900E-01	5.72200E-01	6.19200E-01	4.75900E-01	4.15700E-01	7.97000E-01	1.02200E+00	1.35900E+00
1.08000E+00	9.79500E-01	1.19100E+00	1.38800E+00	1.29800E+00	1.25600E+00	1.30200E+00	1.13000E+00
1.37700E+00	1.04800E+00	1.04900E+00	7.54100E-01	9.79600E-01	9.15600E-01	7.68300E-01	9.36800E-01
1.18100E+00	1.06400E+00	1.22100E+00	1.53600E+00	1.49200E+00	1.59600E+00	1.63300E+00	1.70900E+00
1.75000E+00	1.45900E+00	1.54700E+00	1.59500E+00	1.66600E+00	1.64300E+00	1.51000E+00	1.62900E+00
1.52500E+00	1.39300E+00	1.37300E+00	1.62400E+00	1.64500E+00	1.46700E+00	1.34700E+00	1.18700E+00
9.74200E-01	1.14000E+00	1.16900E+00	1.34300E+00	1.09100E+00	9.84200E-01	1.19200E+00	1.46300E+00
1.35400E+00	1.38000E+00	1.23500E+00	1.27900E+00	1.25100E+00	1.57700E+00	1.37000E+00	1.55800E+00
1.69200E+00	1.68800E+00	1.73000E+00	1.53500E+00	1.42600E+00	1.26300E+00	1.45600E+00	1.57100E+00
1.75000E+00	1.64700E+00	1.53600E+00	1.47100E+00	1.29800E+00	1.30600E+00	1.22300E+00	1.21500E+00
8.33500E-01	9.38300E-01	8.82100E-01	7.04200E-01	8.50600E-01	8.56500E-01	7.67300E-01	8.24900E-01
8.28700E-01	9.13000E-01	1.11600E+00	1.24700E+00	1.26900E+00	1.22300E+00	8.87400E-01	9.24600E-01
8.50400E-01	1.06200E+00	1.11300E+00	9.85900E-01	1.20900E+00	1.24900E+00	1.40100E+00	1.61700E+00

1.43800E+00	1.20200E+00	1.31200E+00	1.46700E+00	1.42700E+00	1.48100E+00	1.65500E+00	1.50500E+00
1.24400E+00	1.20100E+00	1.19300E+00	1.33900E+00	1.27900E+00	1.43600E+00	1.29000E+00	1.25300E+00
1.25500E+00	8.02700E-01	5.27800E-01	5.16900E-01	5.16300E-01	4.18200E-01	1.08300E-01	1.28900E-01
1.22400E-01	3.63800E-01	-3.40700E-02	-8.00500E-03	5.21900E-02	1.10500E-01	-2.66700E-02	1.65200E-02
1.91100E-01	5.13700E-01	5.98800E-01	4.64300E-01	6.56000E-01	5.25000E-01	4.43200E-01	6.63100E-01
7.07500E-01	6.62400E-01	5.40200E-01	7.97300E-01	8.23800E-01	7.61000E-01	7.99200E-01	8.76000E-01
1.21600E+00	1.33000E+00	1.33300E+00	1.09400E+00	1.04500E+00	7.05100E-01	9.98100E-01	9.69300E-01
1.02300E+00	1.07900E+00	9.77200E-01	9.24900E-01	1.25200E+00	1.30900E+00	1.62900E+00	1.94700E+00
2.19800E+00	2.22100E+00	2.07300E+00	2.15100E+00	2.00900E+00	1.79300E+00	1.75500E+00	1.70100E+00
1.78400E+00	1.94600E+00	2.05100E+00	1.91300E+00	1.70300E+00	1.66600E+00	1.39200E+00	1.44500E+00
1.28100E+00	1.32900E+00	1.63500E+00	1.51800E+00	1.46700E+00	1.25000E+00	1.41800E+00	1.33300E+00
1.52200E+00	1.48300E+00	1.27100E+00	8.79800E-01	7.47800E-01	6.98800E-01	2.99800E-01	1.15200E-01
-6.54500E-01	-6.75300E-01	-6.33300E-01	-6.09500E-01	-7.82700E-01	-6.24300E-01	-4.28500E-01	-4.05800E-01
-1.68800E-01	-4.99900E-01	-8.17100E-01	-6.65600E-01	-8.59900E-01	-1.10800E+00	-9.40100E-01	-9.93600E-01
-6.76800E-01	-6.52800E-01	-7.39900E-01	-1.00500E+00	-1.32900E+00	-1.58900E+00	-1.45200E+00	-1.41600E+00
-1.28500E+00	-1.12500E+00	-9.93800E-01	-7.88800E-01	-5.77300E-01	-5.46500E-01	-5.16000E-01	-4.43700E-01
-3.61200E-01	-5.18900E-01	-6.06400E-01	-5.65400E-01	-5.04000E-01	-1.78300E-01	-1.05100E-02	-2.88600E-01
-2.97100E-02	3.62400E-02	-9.27000E-02	-2.11900E-01	-1.46500E-01	4.07500E-02	1.13000E-01	-2.08700E-01
-6.44400E-02	-2.20000E-01	-2.52800E-01	-8.20100E-01	-6.60300E-01	-8.12200E-01	-9.55700E-01	-1.30500E+00
-1.54100E+00	-1.29500E+00	-1.11100E+00	-6.57000E-01	-7.30600E-01	-7.20200E-01	-7.65700E-01	-6.55300E-01
-7.64500E-01	-6.91300E-01	-9.80000E-01	-1.26600E+00	-1.25200E+00	-1.28100E+00	-1.38500E+00	-1.44000E+00
-1.35700E+00	-1.40400E+00	-1.60500E+00	-1.63200E+00	-1.68200E+00	-1.44000E+00	-1.43000E+00	-1.27100E+00
-1.15000E+00	-1.07300E+00	-8.61800E-01	-7.00900E-01	-5.84000E-01	-4.82500E-01	-6.65700E-01	-4.92100E-01
-4.03500E-01	-7.15600E-01	-7.71300E-01	-7.69700E-01	-1.07200E+00	-1.04100E+00	-9.65100E-01	-1.08300E+00
-1.03800E+00	-8.58200E-01	-6.50400E-01	-7.79300E-01	-1.04600E+00	-1.18300E+00	-1.13900E+00	-1.21200E+00
-1.02200E+00	-1.10600E+00	-1.03800E+00	-1.12300E+00	-1.00100E+00	-8.82800E-01	-1.09200E+00	-6.60200E-01
-7.73000E-01	-6.69100E-01	-6.75200E-01	-5.25800E-01	-5.07100E-01	-3.57400E-01	-3.84500E-01	-6.41300E-01
-5.87400E-01	-6.75600E-01	-8.66300E-01	-9.45900E-01	-1.00500E+00	-1.07300E+00	-1.07200E+00	-1.11000E+00
-1.32400E+00	-1.51700E+00	-1.68800E+00	-1.53300E+00	-1.47600E+00	-1.24800E+00	-1.12400E+00	-1.17000E+00
-1.20100E+00	-1.25600E+00	-1.18300E+00	-1.11800E+00	-1.12600E+00	-8.74500E-01	-7.60900E-01	-6.69500E-01
-9.14000E-01	-7.04200E-01	-7.63400E-01	-9.36800E-01	-1.04700E+00	-9.70200E-01	-1.25500E+00	-1.29000E+00
-1.43300E+00	-1.05900E+00	-8.35300E-01	-1.02300E+00	-1.34900E+00	-1.52800E+00	-1.39200E+00	-1.17800E+00
-1.38800E+00	-1.36800E+00	-1.30900E+00	-1.51100E+00	-1.75300E+00	-1.66600E+00	-1.89100E+00	-1.78300E+00
-1.93200E+00	-2.00900E+00	-1.66700E+00	-1.75600E+00	-1.69100E+00	-1.90300E+00	-1.85700E+00	-2.08600E+00
-1.94000E+00	-1.72300E+00	-1.81400E+00	-1.78400E+00	-1.69900E+00	-1.76600E+00	-2.05800E+00	-2.27400E+00
-2.16000E+00	-2.05000E+00	-2.10000E+00	-2.21700E+00	-2.12600E+00	-2.23000E+00	-2.05700E+00	-1.87600E+00
-1.90100E+00	-2.11400E+00	-1.81500E+00	-1.61600E+00	-1.77600E+00	-1.73800E+00	-2.01600E+00	-2.01400E+00
-1.88700E+00	-1.54600E+00	-1.43600E+00	-1.29400E+00	-1.24100E+00	-1.22700E+00	-1.19700E+00	-1.00500E+00
-1.00900E+00	-8.85600E-01	-6.03900E-01	-4.64300E-01	-4.33100E-01	-6.18100E-01	-6.73900E-01	-8.72500E-01
-9.16500E-01	-7.77800E-01	-8.21400E-01	-7.38200E-01	-7.39700E-01	-1.09700E+00	-1.22700E+00	-1.46300E+00
-1.27400E+00	-1.18100E+00	-1.20500E+00	-1.43500E+00	-1.28800E+00	-1.20600E+00	-9.59500E-01	-6.70700E-01
-7.89000E-01	-5.52600E-01	-7.07600E-01	-5.41300E-01	-5.35200E-01	-6.76400E-01	-3.49500E-01	-2.86600E-01
-3.01200E-01	-4.22600E-01	-2.60000E-01	-4.53300E-01	-3.57800E-01	-4.47200E-01	-3.79400E-01	-3.69400E-01
-2.67800E-01	-3.49600E-01	-7.36800E-02	1.47700E-01	1.83300E-01	3.42000E-01	4.81500E-01	5.58000E-01
6.91700E-01	6.96400E-01	9.30100E-01	9.89100E-01	9.47100E-01	6.57300E-01	8.73400E-01	1.03000E+00
9.71900E-01	8.53500E-01	1.04900E+00	1.20800E+00	1.44700E+00	1.42300E+00	1.83200E+00	2.05300E+00
1.83200E+00	1.59900E+00	1.62600E+00	1.56400E+00	1.48800E+00	1.56000E+00	1.65700E+00	1.52200E+00
1.81800E+00	2.04500E+00	1.72800E+00	1.82100E+00	1.67900E+00	1.84100E+00	1.45900E+00	1.46000E+00
1.29700E+00	1.33900E+00	1.37000E+00	1.39000E+00	1.30700E+00	1.16100E+00	1.29100E+00	9.48600E-01
1.24600E+00	1.32000E+00	1.39600E+00	1.53400E+00	1.56900E+00	1.66200E+00	1.85200E+00	1.90900E+00
1.99900E+00	1.92700E+00	1.97600E+00	2.21100E+00	2.14700E+00	1.93000E+00	1.85400E+00	1.89300E+00
2.21700E+00	2.38600E+00	2.34500E+00	2.13400E+00	2.06000E+00	1.95800E+00	2.08900E+00	2.26100E+00
2.28400E+00	2.51900E+00	2.62800E+00	2.47300E+00	2.52700E+00	2.42200E+00	2.31100E+00	2.32200E+00
2.24900E+00	2.01400E+00	1.89300E+00	2.03500E+00	2.27600E+00	2.53800E+00	2.42000E+00	2.10000E+00
1.77500E+00	1.67200E+00	1.37800E+00	1.52300E+00	1.10100E+00	1.10500E+00	1.21000E+00	1.38300E+00
1.56900E+00	1.46500E+00	1.62000E+00	1.49700E+00	1.57800E+00	1.44000E+00	1.30400E+00	1.36200E+00
1.21400E+00	1.03000E+00	8.82100E-01	1.12500E+00	1.21200E+00	1.52300E+00	1.30400E+00	1.47600E+00
1.79200E+00	1.80300E+00	1.61100E+00	1.67000E+00	1.52000E+00	1.31100E+00	1.02900E+00	1.33600E+00
1.19600E+00	8.45900E-01	8.51700E-01	9.79400E-01	6.83900E-01	6.39500E-01	3.99300E-01	3.68600E-01
3.88400E-01	4.87500E-01	6.07800E-01	7.09200E-01	8.28700E-01	6.69700E-01	5.36200E-01	4.19800E-01

Output: Printout (the input parameter) (See 2.2.2.1)

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                 VEHICLE  DYNAMIC  ANALYSIS

                      PROGRAM TIRE

           DYNAMIC SIMULATION OF HEAVE PITCH MOTION

          THIS PROGRAM SIMULATES HEAVE PITCH
          MOTION OF A THREE AXLE VEHICLE OPERATING
          OVER A SPECIFIED PROFILE


           VEHICLE TYPE         - 5 TON TRUCK
           TIRE TYPE            - GOODYEAR 11.00-18
           TERRAIN NO.          - 2 (RANDOM PROFILE)
           TIRE MODEL           - POINT CONTACT

         FORWARD SPEED                   =       18.000  MPH
         TERRAIN ROUGHNESS               =        1.000  INCH RMS


                 VEHICLE FRAME PARAMETERS
         MASS OF HULL                    =      718.600  SLUGS
         BOGIE MASS                      =        6.000  SLUGS
         FRONT UNSPRUNG MASS (EACH)      =       40.590  SLUGS
         MIDDLE UNSPRUNG MASS (EACH)     =       42.090  SLUGS
         REAR UNSPRUNG MASS (EACH)       =       43.450  SLUGS
         PITCH INERTIA OF HULL           =    34924.000  SLUG FT SQ
         PITCH INERTIA OF BOGIE          =        3.000  SLUG FT SQ
         FRONT SUSP TO HULL CG           =       12.500  FT
         BOGIE CONNECTION TO HULL CG     =        2.417  FT
         HULL CG HEIGHT                  =        0.000  FT
         OFFSET,BOG CONN TO HULL PLANE   =        0.000  FT
         BOG CONN TO FRNT STOP           =        2.208  FT
         BOG CONN TO REAR STOP           =        2.208  FT
         OFFSET,BOG CON TO BOG CG        =        0.000  FT
         HALF BOGIE LENGTH               =        2.208  FT
         STOP SIZE                       =         .250  FT
         STIFFNESS FACTOR,BOG-STOP       =       10.000
         STIFFNESS FACTOR,BOG-HULL       =     1000.000
         STOP GAP                        =         .393  FT


                      SUSPENSION PARAMETERS
                          FRONT SUSPENSION,EACH
         STIFFNESS                       =    29976.000  LB/FT
         VISCOUS DAMPING COEFF.(JOUNCE)  =      185.000  LB SEC/FT
         VISCOUS DAMPING COEFF.(RBND)    =      600.000  LB SEC/FT
         JOUNCE TRAVEL                   =         .500  FT
         REBOUND TRAVEL                  =         .500  FT
                          MIDDLE AND REAR SUSPENSIONS
         STIFFNESS                       =    87000.000  LB/FT
         JOUNCE TRAVEL                   =         .700  FT
         REBOUND TRAVEL                  =         .700  FT
         STOP STIFFNESS FACTOR           =       10.000

                      TIRE PARAMETERS
         STIFFNESS                       =    39000.000  LB/FT
         DAMPING                         =       31.100  LB SEC/FT
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TIRE RADIUS	=	1.670	FT
TIRE CONTACT LENGTH	=	1.030	FT
TIRE EFFECTIVE WIDTH	=	.610	FT
TIRE CUBIC STIFFNESS	=	17.096	LB/CU IN
TIRE CUBIC DAMPING	=	57.886	LB SEC/CU FT
TIRE PRESSURE	=	30.000	PSI
TIRE DEFLECTION LIMIT	=	.400	FT
TIRE STIFFNESS FACTOR	=	10.000	

Output: Printout (first page of dynamic simulation results)

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                                                 DYNAMIC SIMULATION
NO.  TIME    FV2       FV3       FV4       FH2       FH3       FH4       YW2       YW3       YW4       Y0        THETA,DEG PHI,DEG
             DEL2      DEL3      DEL4      Y2        Y3        Y4        YB        FY2       FSY3      FSY4
             FFS       FRS       D2Y0      D2YB      D2YW2     D2YW3     D2YW4     D2THETA   D2PHI

 1  0.000 3.06E+03  6.19E+03  6.22E+03  4.68E+02  2.22E+02  3.13E+02  1.62E-02  2.06E-01  6.44E-02  1.16E-01  4.57E-01 -1.84E+00
             6.29E-02  5.63E-02  5.63E-02  1.62E-02  7.06E-01  6.44E-02  1.35E-01  1.87E+03  4.90E+03  4.90E+03

             0.        0.        4.15E-05 -4.97E-03 -3.09E+00 -1.40E+00 -1.89E+00 -2.08E-03 -4.30E+00
 2   .095 2.53E+03  6.78E+03  0.                  2.36E+02  1.67E+03 -0.                  -3.54E-02  1.72E-01  1.93E-01  1.34E-01  6.36E-01  2.67E-01
             3.20E-02  7.78E-02  7.82E-02 -5.04E-02  1.83E-01  1.11E-01  1.61E-01  1.05E+03  6.68E+03  6.71E+03

             0.        0.        7.61E+00  1.02E+01  4.34E+00 -2.99E+01 -1.86E+02  1.09E+00  3.57E+01
 3   .189 5.36E+03  6.78E+02  1.63E+03 -1.75E+02 -8.47E+01 -3.66E+01 -7.23E-01  2.15E-01  2.54E-01  1.26E-01  1.09E+00  7.21E-01
             5.24E-02  1.27E-01  1.11E-01 -6.87E-02  1.38E-01  1.96E-01  1.72E-01  1.70E+03  1.14E+04  9.43E+03

             0.        0.        2.99E+01  3.39E+01  5.79E+01 -2.87E+02 -2.11E+02  1.64E+00 -2.88E+03
 4   .284 1.71E+03  0.        1.10E+03  2.27E+01 -0.                 -1.13E+02 -1.01E-01  2.28E-01  2.12E-01  1.15E-01  1.34E+00 -2.81E-01
             1.40E-01  1.07E-01  1.08E-01 -1.39E-01  8.66E-02  1.40E-01  1.72E-01  2.80E+03  8.64E+03  9.58E+03

             0.        0.        2.58E+01  2.70E+01 -5.93E+01 -2.37E+02 -2.26E+02  4.89E-01  1.38E+03
 5   .379 4.36E+03  6.19E+03  0.                  1.58E+02  1.51E+01 -0.                  -1.07E-01  6.89E-03  2.79E-01  8.39E-02  1.11E+00  3.52E+00
             1.12E-01  6.81E-02  6.97E-02 -7.46E-02  1.51E-03  1.35E-01  1.31E-01  3.80E+03  5.88E+03  6.13E+03

             0.        0.        1.14E+01  8.83E+00 -1.83E+01 -2.47E+01 -1.73E+02 -1.08E+00  3.63E+02
 6   .473 3.58E+03  7.17E+03  7.06E+03 -5.27E+02  1.62E+03  7.10E+02 -4.48E-02  1.22E-02  1.48E-02  1.62E-02  3.45E-01  5.08E-02
             7.66E-02  3.97E-02  3.84E-02 -3.71E-02  3.23E-02  2.10E-02  3.07E-02  1.99E+03  3.53E+03  3.26E+03

             0.        0.       -8.09E+00 -9.19E+00  8.16E+00  5.44E+01  5.49E+01 -4.55E-01 -3.92E+02
 7   .568 0.        1.46E+04  3.99E+04 -0.                  2.22E+03 -1.86E+01 -3.90E-02 -1.35E-01  1.58E-02 -6.06E-02 -4.32E-01  1.94E+00
            -1.01E-02  7.47E-02  7.62E-02 -1.20E-01 -3.03E-02 -1.09E-02 -7.89E-02 -1.02E+03  6.42E+03  6.54E+03

             0.        0.        7.22E-01  6.76E+00 -7.12E+00  1.63E+02 -9.06E+01  2.50E+00  6.22E+01
 6   .663 3.59E+03  5.81E+02  1.65E+04 -3.06E+02 -9.0 E+01  6.82E+02 -8.48E-04 -2.19E-02 -1.47E-01 -1.01E-01 -2.12E-01 -1.65E+00
             1.16E-01  8.04E-02  8.26E-02  9.46E-03 -9.78E-02 -1.61E-02 -1.09E-01  4.12E+03  6.89E+03  7.30E+03

             0.        0.        1.84E+01  1.59E+01 -4.53E+01 -1.82E+02  1.78E+02 -1.00E+00  5.75E+02
 9   .758 7.55E+03  5.59E+03  0.                  1.06E+03 -1.2 E+02 -0.                   3.15E-02 -1.04E-01  1.61E-02 -2.54E-02 -8.08E-02  1.59E+00
             1.01E-01  4.24E-02  4.02E-02  1.47E-01 -1.13E-01 -9.12E-02 -2.91E-02  2.86E+03  3.63E+03  3.42E+03

             0.        0.       -4.83E+00 -7.43E+00  8.34E+01  1.43E+01 -1.11E+02 -1.08E+00 -2.97E+02
11   .852 1.90E+03  1.20E+03  7.34E+03 -2.65E+02 -4.85E+01 -1.09E+03  1.56E-01 -1.10E-03 -4.34E-02 -1.10E-03 -7.26E-01 -5.40E-01
             6.15E-02  6.61E-02  6.54E-02  1.20E-01 -6.82E-02 -3.20E-02 -3.17E-02  8.27E+02  5.79E+03  5.73E+03

             0.        0.        1.87E+00  4.25E+00 -5.72E+00 -1.41E+02  4.74E+00  9.87E-01 -7.20E+01
```

Output: Printout (last page of dynamic simulation results)

```
                                                    DYNAMIC SIMULATION

NO.  TIME    FV2         FV3         FV4         FH2         FH3         FH4         YW2         YW3         YW4         Y0        THETA.DEG PHI.DEG
             DEL2        DEL3        DEL4        Y2          Y3          Y4          Y8          FY2         FSY3        FSY4
             FFS         FBS         D2Y0        D2YB        D2YW2       D2YW3       D2YW4       D2THETA     D2PHI

191 17.992 0.            0.          0.          -0.         -0.         -0.         6.51E-01    4.54E-01    3.30E-01    5.22E-01  -9.37E-01 -1.78E+00

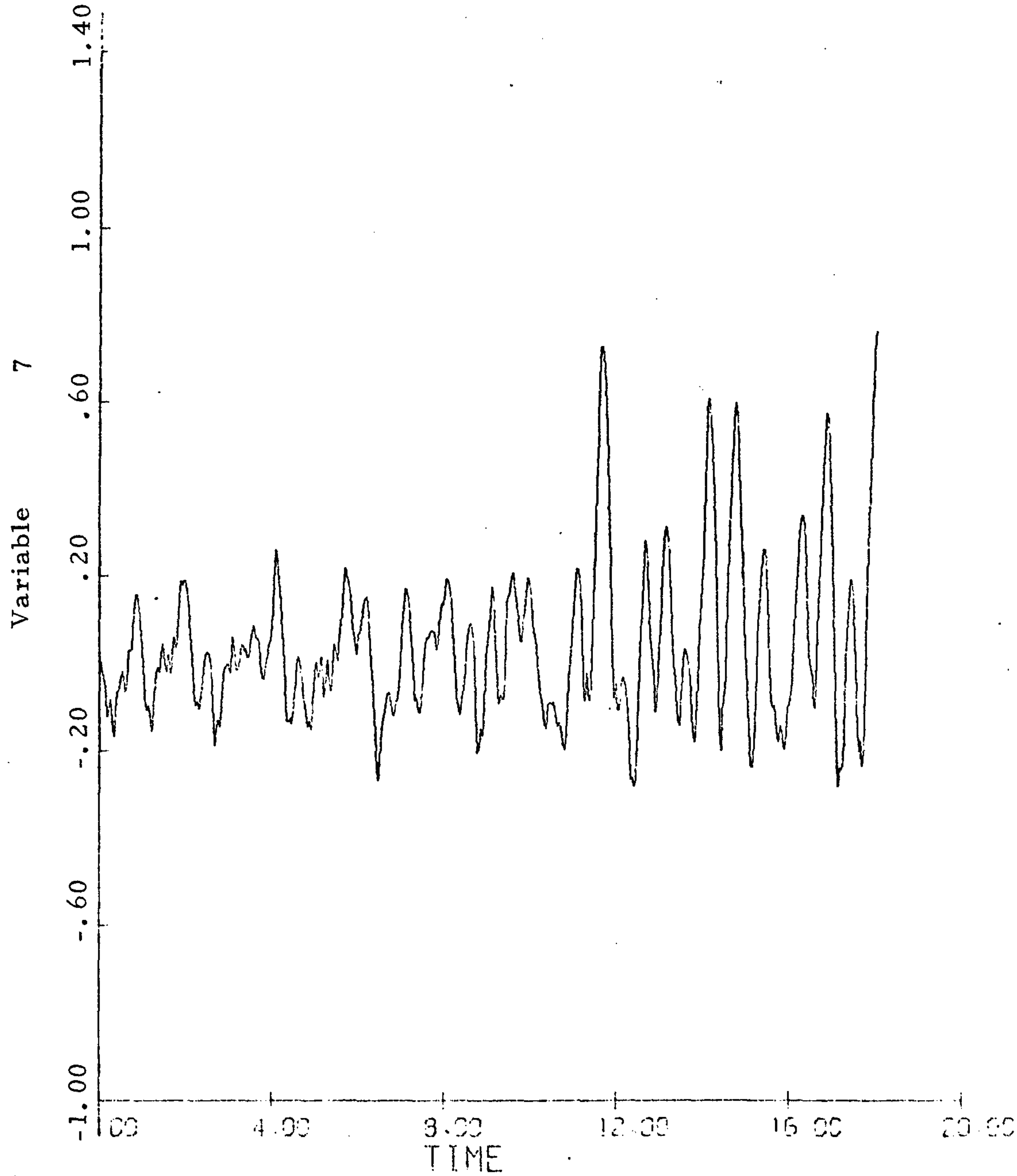
         -1.27E-02  -4.02E-02  -2.68E-02   1.67E-01  -1.44E-01  -1.04E-01   4.82E-01   1.37E+02  -3.92E+03  -1.97E+03

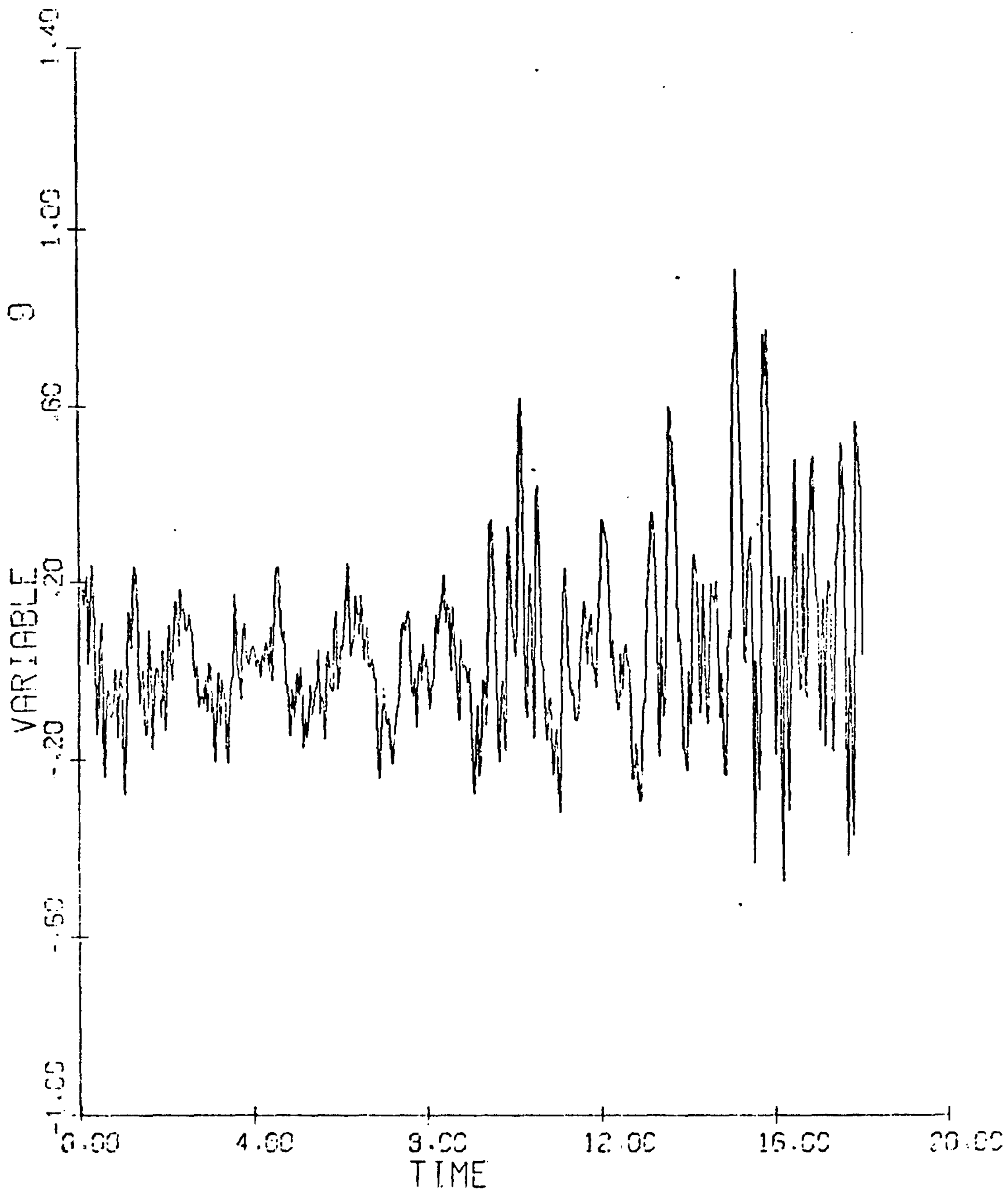
          0.          0.        -4.81E+01  -5.02E+01  -3.56E+01   6.09E+01   1.29E+01  -9.05E-01   2.87E+03
192 18.087 0.            6.41E+03    0.          -0.         -7.59E+02  -0.          7.50E-01  -1.15E-01   9.06E-01    6.36E-01  -7.64E-01  1.34E+01

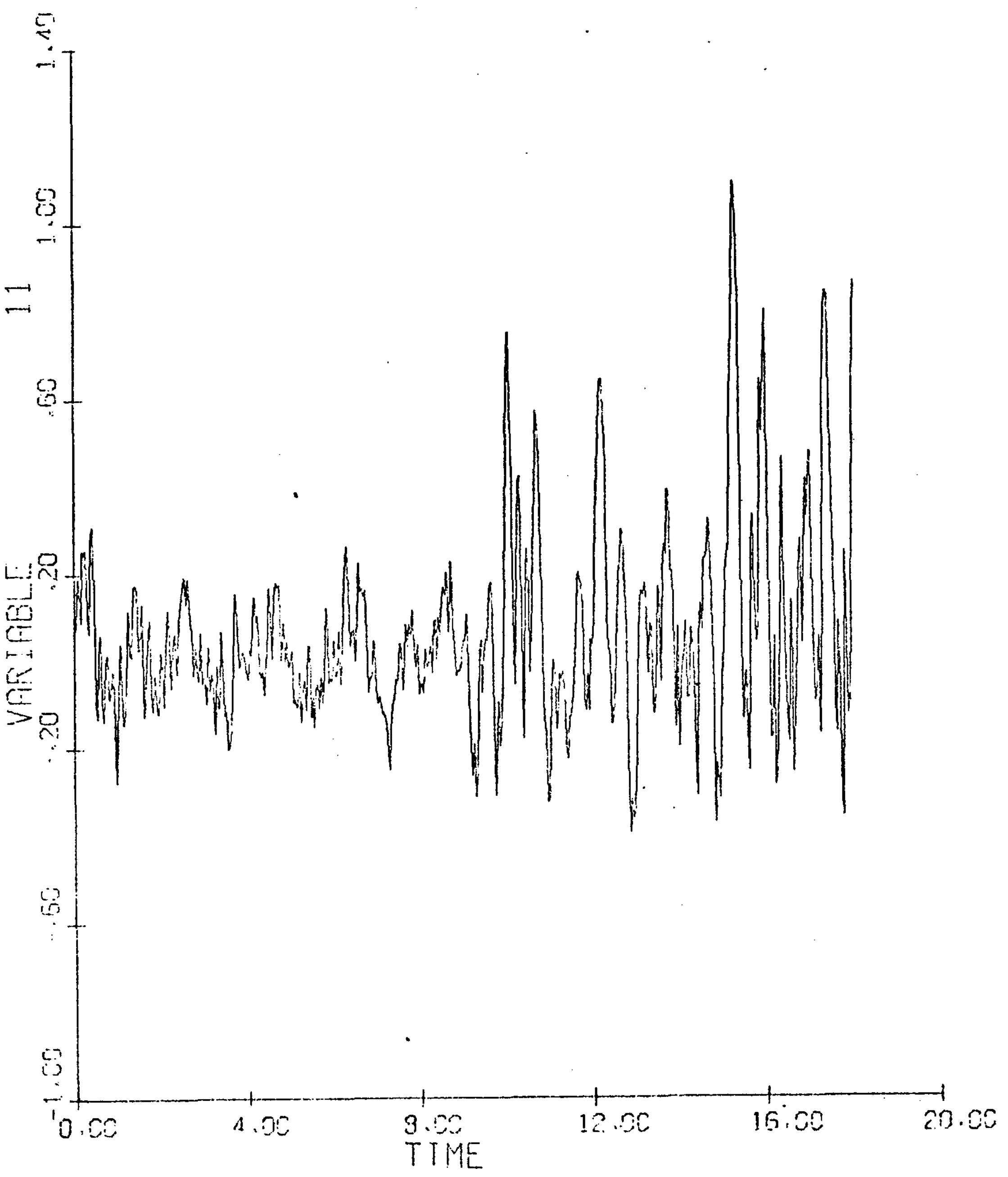
          9.46E-03  -1.51E-01  -1.54E-01   1.68E-01  -1.20E-01  -1.16E-01   6.04E-01  -3.33E+01  -1.22E+04  -1.43E+04

          0.          0.        -1.06E+02  -1.14E+02  -3.14E+01   4.10E+02   2.96E+02  -3.62E+00  -2.77E+03
         SIMULATION TIME       7.740E+01        SECONDS
         TOTAL STEPS  478
```

Output: Plots (See 2.2.2.2)




VARIABLE 9
1.40
1.00
.60
.20
-.20
-.60
-1.00
0.00
4.00
8.00
12.00
16.00
20.00
TIME


VARIABLE 11
1.00
.60
.20
-.20
-.60
0.00
4.00
8.00
12.00
16.00
20.00
TIME

ADDITIONAL INFORMATION

The simulation run, described in this section, was made on a CDC 6400 machine at the Smithsonian Institution Astrophysical Observatory in Cambridge, Massachusetts. The control cards used were:

```
        TACOM, ABBA, CM100K, T600.  R. FISH, FOSTER-MILLER
        RUN(S)
Note -->SETCORE (ZERO)
        LGO.
        CALPLT.
        7/8/9

        Source Deck (See the listing in Appendix A.4)

        7/8/9

        Data Cards

        6/7/8/9
```

The run used 70K (octal) core, and 109 seconds of CPU time. The cost for the run was about $18 (government rate).

3. STEP 2: SHAKER INPUT SIGNALS FROM AXLE DISPLACEMENT RECORDS

In the second step of the recorded simulation control scheme, the axle displacement records created by the vehicle simulation program are converted to the shaker input signals through two tasks shown in Figure 9. The tasks are:

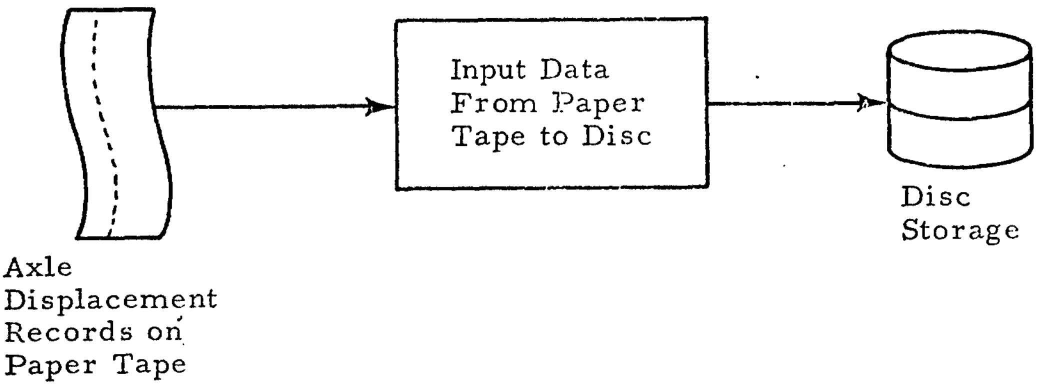
a. Acquire the data generated by the first step and store them on an on line storage medium.

b. Convert the records on the storage medium to time synchronized shaker input signals.

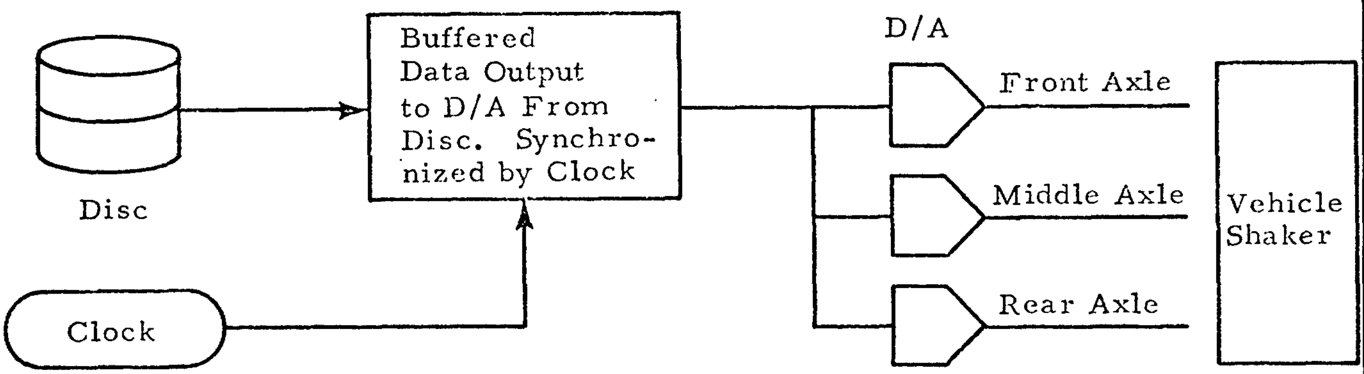
For the control system developed in this effort, the first step involves reading axle displacement data from the paper tapes and transferring them to a magnetic disc unit. The data transfer is an off-line operation and needs to be performed only once for any particular simulation data set (unless the information is destroyed accidentally). In the data set read by the control system, there are four elements: time, front axle displacement, middle axle displacement, and rear axle displacement.

The second task acquires the data from magnetic disc, converts the displacement values to analog signals using D/A converters and transmits them at a time synchronized rate. The time synchronization is achieved by comparing real time signals produced by a crystal clock with the stored time values. The second task involves repeated playback of the records repeatedly because the displacement records are of a finite length.

The following describes the hardware-software aspects of the control system and illustrates its use through an example. Additional details of the system are in Appendix B.



(a) Data File Creation



(b) Operation Control

Figure 9. Details of the Second Step of the Recorded Simulation Control Scheme

3.1 Control System

3.1.1 System Hardware

The second step of the recorded simulation control scheme is implemented using an EAI 590 hybrid computing system which incorporates a PACER 100 (16 bit minicomputer) interfaced to an EAI 580 analog computer, as shown in Figure 10. The interface is such that there is a bidirectional communication and data transfer between the two computers during parallel operation. A magnetic disc system capable of storing two million 16 bit words is connected to the digital processor via a direct memory access channel (DMAC). Input-output by the system is accomplished through a teletype, a printer and a paper tape reader-punch. Key characteristics of these components are summarized in Table 4, with details of the hardware and operations of the components left for the EAI publications listed in the end (references 4, 5, 6 and 7).

For the example used in this manual, the displacement records to be stored in the disc are 18 seconds long, with about 5000 time steps. The records then need about 150K 16 bit words of storage space on the disc. These data are time synchronized by a crystal clock prior to transmission. The clock has a 16 bit counter register and the value stored in the register is compared by the digital processor with the stored signal values. When the values become equal, the displacement data are transferred from D/A converters to the vehicle shaker input electronics. Signal outputs from the D/A converters are bipolar (signed), have a full scale reading of 10 volts, and are scaled such that a full scale output of 10 volts equals 1 foot of axle displacement. They are retrieved from the D/A output trunks on channels one, two and three and then fed to the shaker servo inputs through any required signal conditioners.

In addition to initiating the basic hardware, the user also has to make several hardware patch board connections on the analog computer. The clock/timer requires a connection between the 1 KHz crystal oscillator output and the clock's carry in input. Also the control program, described in the next section, needs the 1 millisecond clock output to be connected to the clock carry in input.

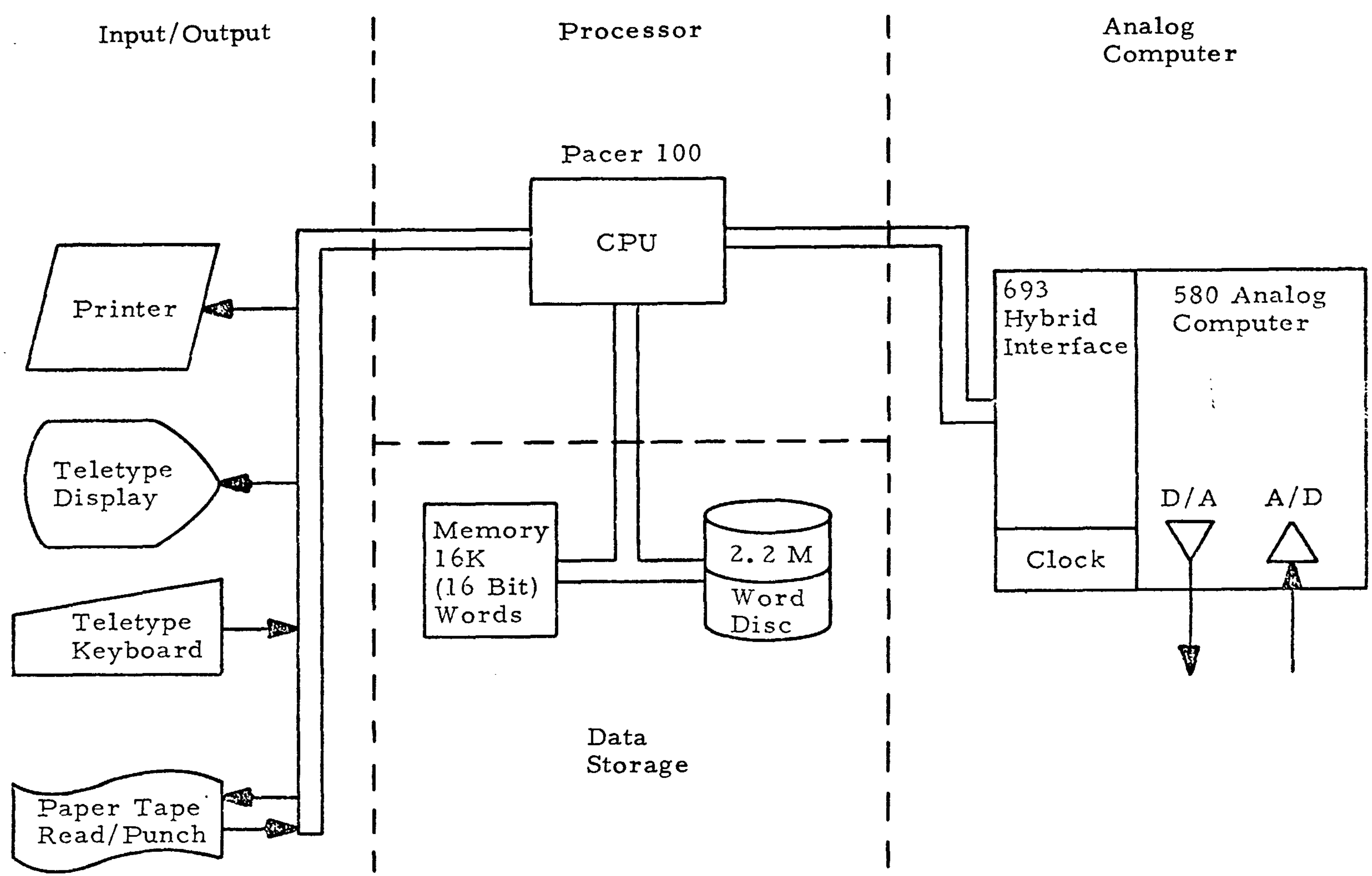


Figure 10. Schematic Diagram of the Control System Hardware

Table 4. Control System Hardware

PACER 100 Computing System
- 16,384 16-bit words of core memory
- Hardware multiply divide
- Priority interrupt system
- Memory protect system
- Power fail/auto restart system
- Five universal controller positions
- 1 Microsecond memory cycle

Direct Memory Access Channel (DMAC)
- Provides for I/O concurrent with computation on cycle stealing basis
- 1 Million words/second

Interval Timer/Real Time Clock
- Provides a high resolution 16 bit real-time clock
- Timer update signal source for four PACER interval timers

Disc Cartridge Controller and One Dual Disk Drive on DMAC
- Provides 1.1 million words of storage on one fixed platter
- Provides 1.1 million words of storage on one removable platter

Hybrid Device Interface 693
- Parallel processor control
- Logical control, sensing and interrupts
- Coefficient device setting
- Data monitoring/display
- Eight channels D/A multiplication (15 bit)
- 15 Channels A/D conversion (13 bit)

Input/Output Devices
- High speed paper tape reader, 300 characters/sec.
- High speed paper tape punch, 120 characters/sec.
- Teletypewriter station (console device), ASR 33
- Line printer, 80 column
- CPU control front panel

Software Systems
- MHDOS, moving head disc operating system
- FORTRAN IV compiler
- Assembler
- BTE, basic text editor
- CIG, core image generator
- HOI, hybrid operations interpreter
- COP, control options processor
- FIU, file interactive utility
- RTL, run time library
- HLR, hybrid linkage routines
- Applications software packages

3.1.2 System Software

Two programs are required to operate the hardware described in the previous section. The first program, called "File Builder Program," reads the paper tapes containing the axle displacement records, packs the data in a buffer and writes them on a disc file as shown in Figure 9(a) (see Appendix B.2.1 for details). The second program, called "Control Program," retrieves the records from the disc storage file, loads them into D/A converters and transmits them at a real-time synchronized rate. This program, which performs Task 2 shown in Figure 9(b), is described in detail in Appendix B.2.2.

The file builder program loads data in blocks of 10 time steps into the buffer before transferring them to a magnetic disc storage file. The loading is continued until the end of the record is indicated by the buffer filled with minus one. The data file on the disc is then rewound and the file is scanned for bad data points. A bad data point is defined as the one for which the time value is outside the -1 to 20 range or an axle displacement value is outside the -1 to +1 foot range. (This definition is valid for the example described in the next section and may have to change depending on the time length of the records or expected values of the axle displacements.) The file is then scanned for such bad data points, 10 time steps at a time, in the buffer and if a bad point is found the 10 steps in the buffer are printed on the line printer with an error message requesting the user to correct the data point. The user has to respond with correct values for the buffer data, which are incorporated by the program through backspacing and overwriting the buffer back to the disc. This scanning process is continued until the end of the disc file is reached.

The control program initializes control data and positions them at the start of the sample. Then it waits until sense switch A, shown in Figure 11, is turned on to begin transmission. Once the transmission is initiated, the program continuously cycles the records until the user terminates the program by turning sense switch B on. During data transmission the program retrieves blocks of 10 time steps from the disc and loads them into a buffer in core memory. The next operation is performed in two steps.

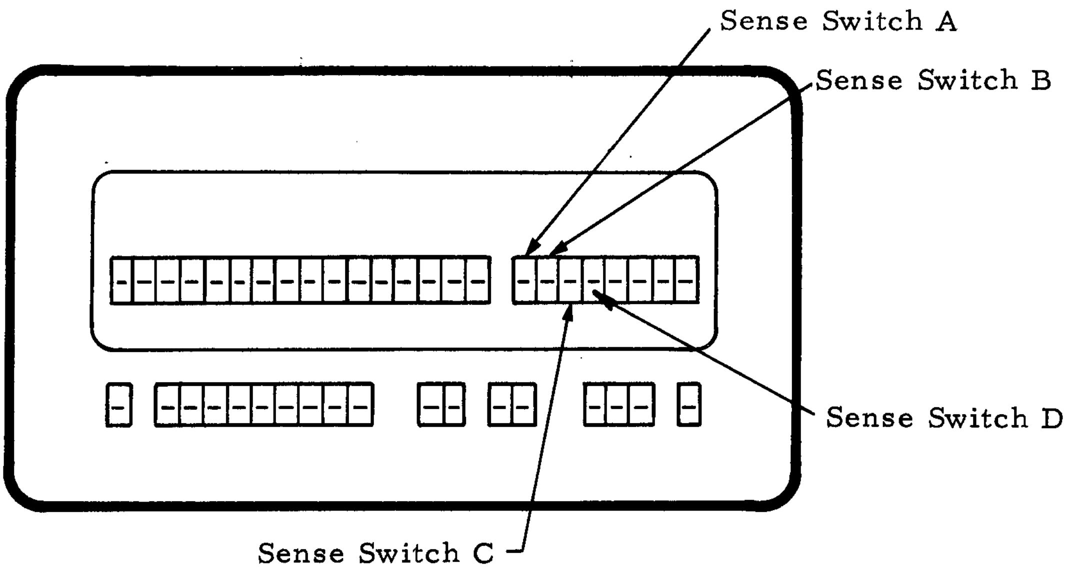


Figure 11. PACER 100 Control Panel

In the first step, the digital values are loaded into a buffer and then supplied to the D/A registers. In the second step, the three D/A registers, now pre-loaded with the front, middle and rear axle displacement values, transfer the signals through the output circuitry at the correct time. After the transfer, the D/A registers are preloaded with the next time step values and the program again waits for the correct time. The data transmission is continued for the 10 time steps before the next block is retrieved from the disc. If the last block has been transmitted, the disc file is rewound and the record is repeated.

Time synchronization mentioned above is achieved by a clock-timer which works by counting down 1 KHz pulses, put out by a hybrid clock, from an initial value to zero. The control program compares the counter value to the corresponding time value stored with the displacement records and when the real-time value becomes less than the stored value, the program allows the transmission to take place.

3.2 User Instructions

Instructions for using the control system in terms of commands and operations required to execute the file builder program and the control program are described in the following. Details of the commands used in communication with the operating system are, however, not discussed because they can readily be found in the EAI reference manuals (reference 4, 5, 6 and 7). Also the procedures for program editing, compilation and load module generation are not discussed here, but are presented in Appendix B.3.

There are certain assumptions made in developing the software and user instructions for the control system:

a. The time values to be stored are less than 20 seconds (i.e., record length is $\leq$ 20 seconds).

b. The values of the axle displacements are between $\pm$1 foot.

c. The number of time steps is less than 30,000.

d. The interval between the time steps is more than 2 milliseconds.

The first two assumptions are used to detect bad data points when the file builder program scans the input data. The third assumption ensures that the disc storage space will not be filled up and the final assumption prevents the time synchronizing devices from losing synchronization. The first two restrictions are easy to change by appropriately altering the file builder program. But the last two restrictions cannot be changed easily because of the limitations of the existing hardware.

3.2.1 File Builder Program Operation

The file builder program (described in Appendix B.2.1) reads the axle displacement records from paper tapes, stores them on disc, prints them (optional), and scans them for bad data points. Before executing the program, however, the user must initialize a disc file, for the program output, on logical unit 21 via a command input to the operating system:

Example #N, FILE1, 21, 3, 130 ↵

where

#N	=	command to monitor to create a disk file
FILE1	=	name given to file
21	=	logical unit file created on
3	=	file type, data file = 3
130	=	words/record for data file in octal
↵	=	carriage return.

The user must then load the core image file of the program from disc into core memory:

Example #L, FILEBLD, 22 ↵

where

#L	=	calls loader program
FILEBLD	=	name of file builder core image file
22	=	logical unit number used by loader in octal. (Do not use 21, because it is already used in the previous step.)

Execution of the loaded program requires input of the executions address:

Example #G, 1000 ↵

where

#G	=	command to link to execution address
1000	=	standard execution address, octal.

Control of the computer is now transferred to the file builder program and a message is printed by the program to notify the user that it is ready for execution. The user then positions the paper tape in the reader, sets the data (sense) switches to implement the option he wishes, and hits the console carriage return to initiate execution. The message and the data switch options are:

"FILE CREATION PROGRAM"
"SET DATA SWITCHES A-D"
"HIT CARRIAGE RETURN TO EXECUTE."

User response:

DATA SWITCH A (ON) = List data as input
DATA SWITCH B (ON) = End program (at any point)
DATA SWITCH C (ON) = Pause before input each step
DATA SWITCH D (ON) = Skip input and go to scan (see Figure 11).

During execution of the program, the axle displacement records are read from paper tape and stored in a buffer in memory. After data for 10 time steps have been read, the buffer data are transferred to the disc file (formats for data input and storage are in Appendix B.4). The program continues the process until it encounters a time value of -1*. When a -1 is detected, the program asks the user if he wishes to store the value to mark end of the record or treat it as the physical end of the tape and read the next paper tape as a continued record:

"-1 INPUT, TYPE 0 TO SKIP, ELSE 1"

User response:

1	which means store -1 as data, because it is end of the record
0	which means skip -1, because the record is continued on the next paper tape

At the end of data the user should input enough records starting with minus one to fill out the last buffer. The disc then encounters -1 in the last time entry, initiating the program to write an end of file mark and close the disc file. After the file is closed the program enters the scanning phase, in which the program checks the created file for time values outside the permissible values of 0 to 20 seconds, and axle displacement values outside the plus or minus one (foot) range. For scanning operation the data are read into the buffer and if a bad value is detected, the data in the buffer are printed on the line printer. Also, a message is printed at the console device asking for the bad data's buffer position and new value:

"INPUT ID # OF BUFFER TO CHANGE AND NEW VALUE, I2, E12.5"

"ID.GE.41 STOPS"

---

*Using -1 indicator this way allows the user to stop the tape input at physical end of a tape before the actual end of the record.

The user then must input the element number and a new value to correct the bad entry.

Example 04+0.12345E+00

Which means: reset element No. 4 (rear axle displacement of the first time step; the element numbers are assigned sequentially in the data block) to 0.12345. After the correction is made, the program prints the message again and the process is repeated until the user indicates end of correction by assigning a value more than or equal to 41 to the element number. The program then backspaces the file by one block, overwrites the bad data and resumes scanning. The scanning operation is completed when end of the file is reached.

3.2.2 Control Program Operation

The control program obtains the displacement data from the disc and generates time synchronized shaker input signals through the digital to analog converters. This program requires the user to position the data file to be transmitted on logical unit 21 (octal) and connect the hybrid clock to the digital timer input. Positioning of the disk file is accomplished by a monitor command input at the console:

Example #P, FILE1, 21

where

#P = command to open disk file
FILE1 = name of data file to be positioned
21 = logical unit file opened on, octal.

The clock/timer requires a jumper plug be installed from the 1 kilohertz output of the hybrid clock to the clock/timer carry in input. Then the clock mode controls are set to run with a frequency of 1 megahertz (details on operation of the hybrid clock can be found in the EAI reference manuals, i.e., references 4, 5, 6, 7 at the end.

Execution of the control program requires loading of the core image file of the program from the disc and then branching to the execution address:

Example   #L, CONTPG, 22 ↵

#G, 1000 ↵

(These arguments are described previously.) Control of the computer is now transferred to the control program, which prints a message to the console device and begins testing data switch A for start of transmission:

"PROGRAM SHAKER"
"LU=21 FOR DATA FILE"

When data switch A is turned on, the program begins transmission of the three axle displacement signals, which are brought out at the D/A outputs on the analog patch board. Once transmission begins the program will continue cycling through the data set until the user terminates the program by turning data switch B on, at which point the program prints a message on the console device and control is returned to the monitor:

"END PROGRAM"

3.3 Illustrative Example

The axle displacement records generated by the illustrative simulation in 2.3 are converted to shaker input signals through the instructions given in the previous section. These axle displacement records are 18 seconds long and include 4780 time steps.

The signal outputs from D/A are recorded on a strip chart recorder and are shown in Figures 12, 13 and 14 along with the corresponding plots of the displacements obtained from the simulation run. As shown in the figures, the control system succeeds in providing outputs which are time synchronized and are identical to the digital axle displacement records.

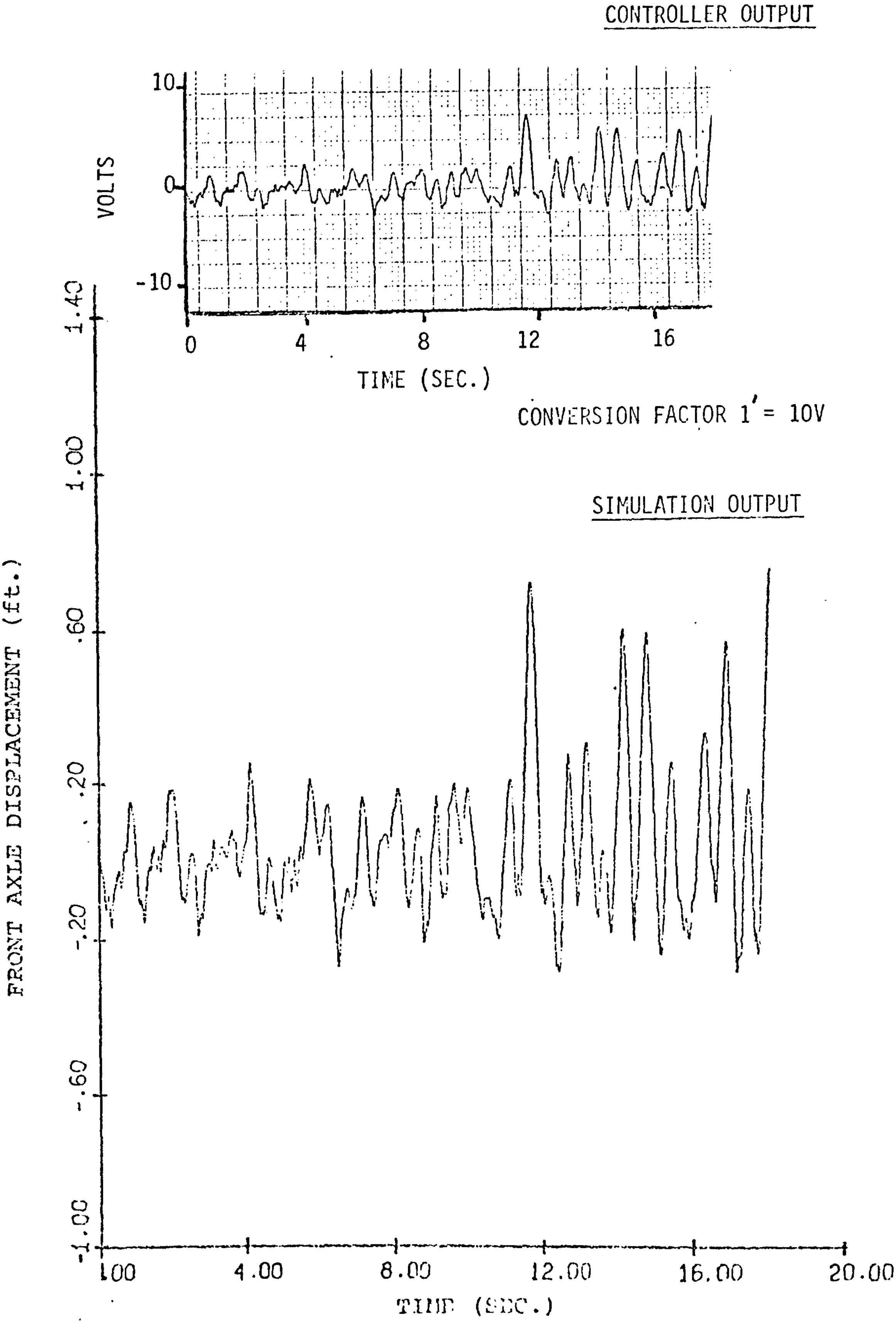


Figure 12. Comparison of the Simulation and the Controller Outputs for the Front Axle Displacement

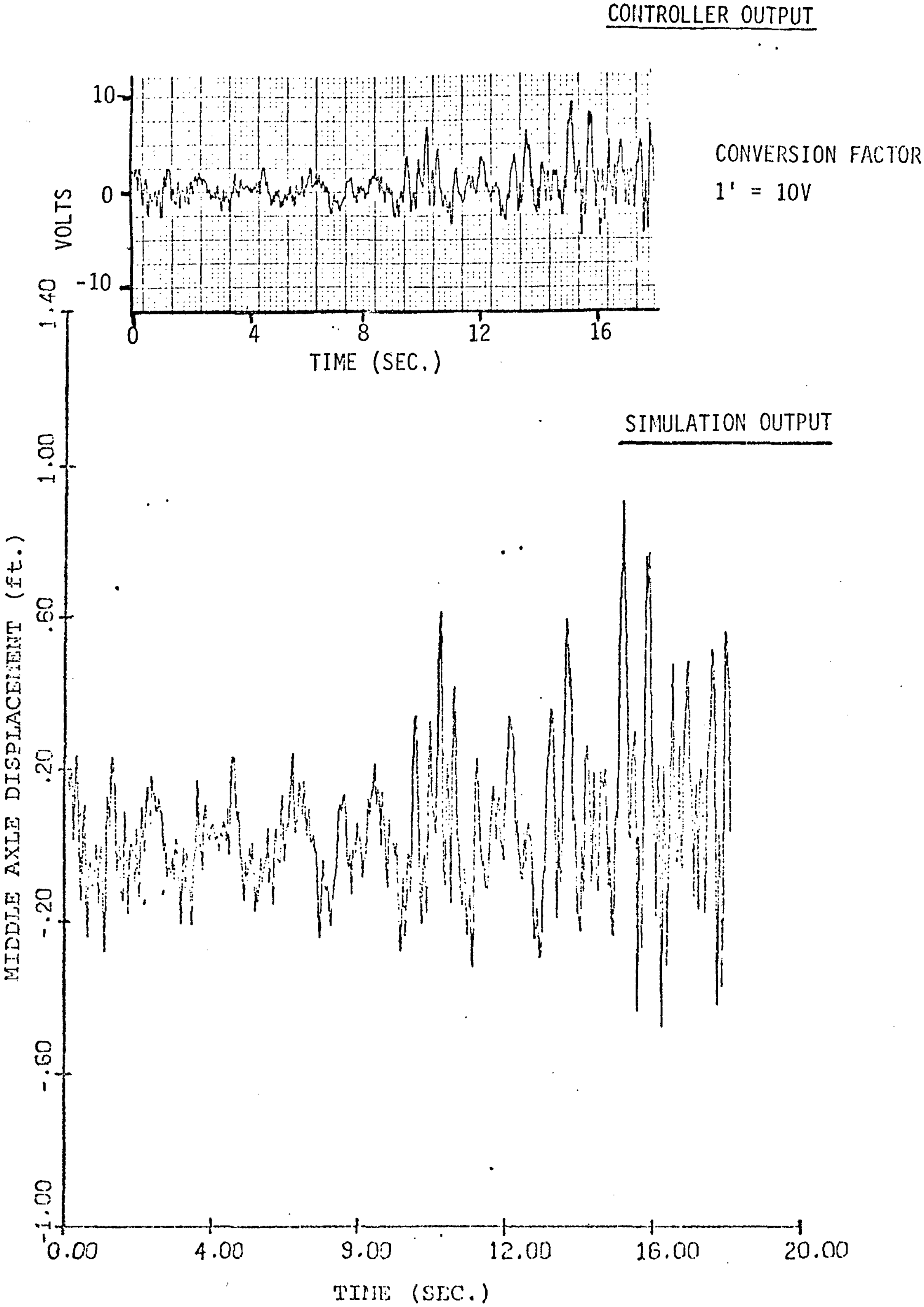


Figure 13. Comparison of the Simulation and the Controller Outputs for the Middle Axle Displacement

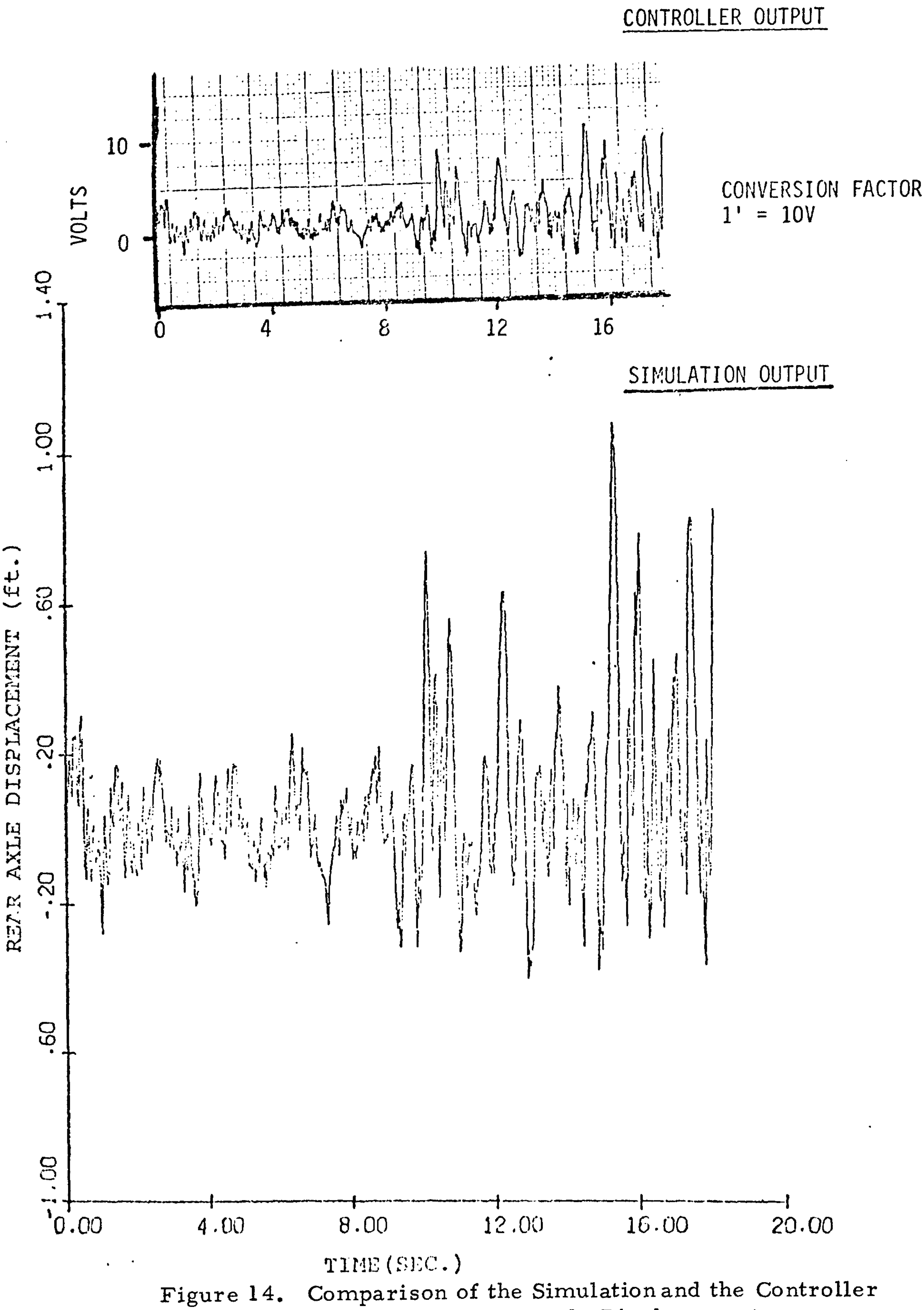


Figure 14. Comparison of the Simulation and the Controller Outputs for the Rear Axle Displacement

APPENDIX A

DETAILS OF THE VEHICLE SIMULATION PROGRAM

The dynamic simulation program used for generating axle displacement records was introduced in Section 2. That section also discussed use of the program and illustrated the use with an example. In Appendix A, further details of the computer program are provided.

A.1 Principal Program Nomenclature

The variables used in the vehicle simulation program are defined in this section along with the corresponding symbols used in the analysis (reference 1). All program variables are in ft-lb-sec units except where indicated to the contrary. (In the input-output operations, however, the variables may not be in the standard ft-lb-sec units, as mentioned in Section 2.2.)

Program Variable Name	Symbol	Explanation
A	a	Half of bogie length
ABC	b''	Distributed (cubic) tire damping constant in the adaptive footprint model
ADCT(I)		$\cos\theta$
ADDT	$d\theta$	Tire sector size
ADDX(I)	δx	Distance of the ith tire sector periphery point from the nearest ground point (See Figure A-3)
ADSDT		$\sin\left(\frac{\delta\theta}{2}\right)$
ADST(I)		$\sin\theta$
ADTH(I)	θ	Angular position of the ith tire sector (See Figure A-3)
ADTT(I)		$\tan\theta$
AKC	k''	Distributed (cubic) tire stiffness in the adaptive footprint model

Program Variable Name	Symbol	Explanation
AL(I)		Contact length for the ith sector (See Figure A-3)
AL1(I)		Contact length of the part away from the vertical for the ith sector (See Figure A-3)
AL2(I)		Contact length of the part towards the vertical for the ith sector (See Figure A-3)
APHI(I)	ϕ_i	Ground slope corresponding to ith sector
BS	B	Tire effective width
BT	b	Tire damping constant
B2V	B_{2v}	Shock absorber damping constant
B2VJ	B_{2vj}	Shock absorber damping constant, jounce
B2VR	B_{2vr}	Shock absorber damping constant, rebound
CONL	L	Equilibrium tire footprint length
CPHI		$\cos\phi$
CTHETA		$\cos\ \Theta$
DDEL(I)	$\dot{\delta}(\theta)$	Radial revlative velocity for the ith sector
DDEL2	$\dot{\delta}_2$	Suspension relative velocity for front suspension
DDEL3	$\dot{\delta}_3$	Suspension relative velocity for middle suspension
DDEL4	$\dot{\delta}_4$	Suspension relative velocity for rear suspension
DELR(I)	$\delta(\theta)$	Radial deflection for ith sector (see Figure A-5)
DEL2	δ_2	Suspension displacement for front suspension
DEL3	δ_3	Suspension displacement for middle suspension
DEL4	δ_4	Suspension displacement for rear suspension
DELTA(I)		Vertical deflection corresponding to ith sector (See Figure A-5)

Program Variable Name	Symbol	Explanation
DER(M)		Derivative of the state variables
DPHI	$\dot{\phi}$	Bogie pitch velocity
DTHETA	Θ	Hull pitch velocity
DTIME		Time step, dt
DYB	$\dot{Y}_b$	Bogie heave velocity (positive upwards)
DYW	$\dot{Y}_w$	Axle heave velocity
DYW2	$\dot{Y}_{w2}$	Front axle heave velocity
DYW3	$\dot{Y}_{w3}$	Middle axle heave velocity
DYW4	$\dot{Y}_{w4}$	Rear axle heave velocity
DYX(M)		Terrain slope for the Mth ground point
DY0	$\dot{Y}_0$	Hull heave velocity
DY2		Rate of change of ground elevation for front wheel
DY3		Rate of change of ground elevation for middle wheel
DY4		Rate of change of ground elevation for rear wheel
D2PHI	$\ddot{\phi}$	Bogie pitch acceleration
D2THETA	$\ddot{\Theta}$	Hull pitch acceleration
D2YB	$\ddot{Y}_b$	Bogie heave acceleration
D2YW2	$\ddot{Y}_{w2}$	Front axle heave acceleration
D2YW3	$\ddot{Y}_{w3}$	Middle axle heave acceleration
D2YW4	$\ddot{Y}_{w4}$	Rear axle heave acceleration
D2Y0	$\ddot{Y}_0$	Hull heave acceleration
FBT(I)		Damping force, ith sector
FBS	F_{bs}	Rear stop force
FB2F	F_{b2f}	Front suspension dry friction force

Program Variable Name	Symbol	Explanation
FB2V	F_{b2v}	Front suspension shock absorber force
FB3F	F_{b3f}	Middle suspension dry friction force
FB4F	F_{b4f}	Rear suspension dry friction force
FC2		Vertical force from each of the front tires, assuming no wheel hop
FC3		Vertical force from each pair of the middle tires, assuming no wheel hop
FC4		Vertical force from each pair of the rear tires, assuming no wheel hop
FFS	F_{fs}	Front stop force
FHG(I)		Force component parallel to ground for the ith sector in adaptive footprint model
FH2	F_{h2}	Horizontal force from each of the front tires
FH3	F_{h3}	Horizontal force from each pair of the middle tires
FH4	F_{h4}	Horizontal force from each pair of the rear tires
FKT(I)		Carcass stiffness force for the ith sector (See Figure A-5)
FK2	F_{k2}	Front suspension spring force
FK3	F_{k3}	Middle suspension spring force
FK4	F_{k4}	Rear suspension spring force
FNG(I)		Force component normal to ground for the ith sector in adaptive footprint model
FP(I)		Pressure force for the ith sector (See Figure A-5)
FSTOP2	F_{stop2}	Stop force, front suspension
FSTOP3	F_{stop3}	Stop force, middle suspension
FSTOP4	F_{stop4}	Stop force, rear suspension

Program Variable Name	Symbol	Explanation
FSX3	F_{sx3}	Horizontal force at each of the bogie and middle suspension connections
FSX4	F_{sx4}	Horizontal force at each of the bogie and rear suspension connections
FSY3	F_{sy3}	Vertical force through middle suspension
FSY4	F_{sy4}	Vertical force through rear suspension
FTIME		Simulation time limit
FV2	F_{v2}	Vertical force from each of the front tires
FV3	F_{v3}	Vertical force from each pair of the middle tires
FV4	F_{v4}	Vertical force from each pair of the rear tires
FXX	F_h	Horizontal tire force in adaptive foot model
FX2	F_{x2}	Horizontal force at each of the hull and front suspension connections
FX34	F_{x34}	Horizontal force at each of the hull and bogie connections
FYY	F_v	Vertical tire force in adaptive footprint model
FY2	F_{y2}	Vertical force through front suspension
FY34	F_{y34}	Vertical force at each of the hull and bogie connections
G(M)		Difference between terrain and wheel slopes for the Mth point in the rigid tread band model
GB	G_b	Rear stop gap
GF	G_f	Front stop gap
GG	GG	Hull CG elevation from hull plane
HS	h_s	Stop size
HSTOP	H_{stop}	Stiffness factor, bogie-hull (See Note 2 in 2.2)
IB	I_b	Pitch inertia of bogie

Program Variable Name	Symbol	Explanation
IDAMP(I)		Ground contact index IDAMP(I) = 0 if ith sector out of ground contact = 1 if ith sector in ground contact
IH	I_h	Pitch inertia of hull
IPHS		Total number of ground points included in a simulation phase
ISCHEM		Adaptive model scheme number (see description of subroutine ADAPT, A.2.11)
ITIRE		Tire model number ITIRE = 1 Point contact = 2 Rigid tread band = 3 Fixed footprint = 4 Adaptive footprint
IXAX		X axis index IXAX = 1 if axis is TIME in plots = 0 if axis is XREAR in plots
IXT		Point numbers on plot
JFIN		Total number of simulation steps
JGR		Ground point number corresponding to wheel center
JL		Number of ground points in half of the contact length
JMAX		Total number of ground points in a simulation (e.g., 5000)
JNOD		Ground point number corresponding to a tire sector
JN2	Jn_2	Jounce clearance, front suspension
JN3	Jn_3	Jounce clearance, middle and rear suspensions
JPHS		Number of steps in a simulation phase
JPL		Total number of points in a plot
JR		Number of ground points in terrain length equal to tire radius
JREAR		Serial number of a simulation step

Program Variable Name	Symbol	Explanation
JSTP		Margin at ends of a simulation phase
K2	K_2	Front suspension stiffness
K3	K_3	Middle and rear suspension stiffness
KPHS		Ground point serial number in a simulation phase
KSTOP	K_{stop}	Stop stiffness factor, bogie-stop (see Note 2 in Section 2.2)
KT	k	Tire stiffness
L2	L_2	Distance from front suspension to hull CG
L3	L_3	Distance from bogie connection to hull CG
LIMP		Limit on number of data points in a plot
LPHS		Serial number of a simulation phase
MB	M_b	Bogie mass
MH	M_h	Hull mass
MFF		Total number of ground points in tire contact length
MM		Number of simulation steps before each printing
MW		Number of ground points between rear and front wheel centers
M2	M_2	Front unsprung mass, each
M3	M_3	Middle unsprung mass, each
M4	M_4	Rear unsprung mass, each
NADS		Number of sectors on each side in adaptive footprint tire model
NAD2		Total number of tire sectors = 2NADS + 1
NBACK		NADS + 2
NPLT(M)		Variable number of the Mth variable to be plotted

Program Variable Name	Symbol	Explanation
NPLTM		Total number of variables to be plotted
NSG(I)		Difference between the ground point numbers corresponding to the ith sector and the wheel center
NW		Ground points between rear and middle wheel centers
NXT		Number of simulation steps skipped between each point in plots
ODYX(M)		Slope of the Mth point in unfiltered terrain profile
OTER(M)		Elevation of the Mth point in unfiltered terrain profile
PHI	ϕ	Pitch angle of bogie (forward pitch is positive)
PLT(M, I)		Value of Ith point in the Mth curve to be plotted
PLSTP		End point of plot, as measured by rear wheel center horizontal distance
PLSTR		First point of plot, as measured by rear wheel center horizontal distance
PRESS	p_i	Tire inflation pressure
RAD	r	Tire radius
RB2	Rb_2	Rebound clearance, front suspension
RB3	Rb_3	Rebound clearance, middle and rear suspensions
SB	S_b	Distance between bogie connection and bogie CG
SBS	S_{bs}	Distance between bogie connection and rear stop
SDYX		Sum of terrain slopes under tire contact length
SFS	S_{fs}	Distance between bogie connection and front stop
SN	n	Stop stiffness factor for suspensions (see Note 2 in Section 2.2)
SPEED	V	Vehicle forward speed

Program Variable Name	Symbol	Explanation
SPHI		Sin ϕ
ST(M)		Terrain slope for the Mth ground point counted from wheel rear
STGAP	St_{gap}	Unloaded gap between stop and bogie
STER		Sum of terrain elevations under tire contact length
STHETA		Sin Θ
SW(M)		Wheel slope for Mth point from wheel rear
S34	S_{34}	Distance between hull plane and bogie connection
TDEF2		Tire deflection, front tire
TDEF3		Tire deflection, middle tires
TDEF4		Tire deflection, rear tires
TER(I)	y_o	Elevation of the ith ground point in filtered profile
TERI		Terrain elevation under a wheel center at equilibrium
TERI2		Terrain elevation under front wheel at equilibrium
TERI3		Terrain elevation under middle wheel at equilibrium
TERI4		Terrain elevation under rear wheel at equilibrium
THETA	Θ	Pitch angle of hull (forward pitch is positive)
TIME	t	Simulation time
TLENT		Total tire contact length ($= \Sigma$AL(I))
TLIM		Tire deflection limit
TSTIF	T_{stif}	Stiffness factor for tire (see Note 2 in Section 2.2)
WEIGHT	W	Equilibrium weight on a tire

Program Variable Name	Symbol	Explanation
WTR2		Equilibrium weight on front tire
WTR3		Equilibrium weight on middle tire
WTR4		Equilibrium weight on rear tire
XC(M)		Distances of the possible contact points from wheel center vertical
XDEL	dx	Distance between the successive ground points
XREAR		X-coordinate of rear wheel center
YB	Y_b	Heave displacement of bogie CG
Y0	Y_0	Heave displacement of hull CG
Y1		Height of wheel center from ground reference plane
Y2		Terrain elevation at front wheel center
Y3		Terrain elevation at middle wheel center
Y4		Terrain elevation at rear wheel center
YHS		The larger segment in partial contact case (see Figure A-4)
YI1		Initial height of the wheel center from ground reference plane
YI12		Initial height of the front wheel center from ground reference plane
YI13		Initial height of the middle wheel center from ground reference plane
YI14		Initial height of the rear wheel center from ground reference plane
YPLT(M)		Value of the Mth plot variable
YRMS		RMS value of the terrain profile
YSP2	Y_{sp2}	Initial deflection of the front suspension
YSP3	Y_{sp3}	Initial deflection of the middle suspension
YSP4	Y_{sp4}	Initial deflection of the rear suspension

Program Variable Name	Symbol	Explanation
YST2		Initial deflection of the front tires in first three tire models
YST3		Initial deflection of the middle tires in first three tire models
YST4		Initial deflection of the rear tires in first three tire models
YTER(M)		Possible wheel center elevations for rigid tread band
YW	y_1	Displacement of wheel center (axle)
YW2	Y_{w2}	Displacement of front axle (shaker input signal)
YW3	Y_{w3}	Displacement of middle axle (shaker input signal)
YW4	Y_{w4}	Displacement of rear axle (shaker input signal)
ZHS		The smaller segment in the partial contact case (see Figure A-4)

A.2 Subroutine Description

The vehicle simulation program includes 18 subroutines interfaced with the main program as shown in Figure 5. In addition the program needs seven CALCOMP subroutines (INITPLT, AXIS, SCALE, NUMBER, LINE, PLOT and FIN) and one system subroutine (SECOND). Each of these subroutines perform specific functions and therefore the program has a modular structure in which changes can be accomplished just by altering the relevant subroutine and not the whole program. Table A-1 describes briefly functions of each of the subroutines.

In order to understand the programming details of the subroutines dealing with the tire models (POINTC, RTREAD, FPRINT, APRINT, ADORG and ADAPT), with the vehicle model (SUSP and BOGIE), with terrain profile (PROFILE) or with the system state equations (STEQU) a study of reference 1 is a prerequisite. Once such study has been undertaken, details of how the models are incorporated in the computer program can be obtained from the following. Also described in this section are subroutines DYSYS, RKDIF, PSTORE and VPLOTS which deal with dynamic simulation and plotting part of the program. Subroutines IOLAB, IOLABD, IOLAB2 and PROGIO deal with the data input function of the program and are self explanatory. The rest of the subroutines are described, beginning with Main Program.

A.2.1 Main Program

The main program acts as an interface for various functions of the program. The first function of the program, i.e., data input, is carried out by the main program through subroutines PROGIO and PROFILE. The data obtained from subroutine PROGIO are converted to proper units: i.e., SPEED is converted from mph to ft/sec, YRMS from inch to feet, inflation pressure PRESS from psi to psf and the distributed stiffness AKC from $lb/in.^3$ to lb/ft^3.

Index IPHS is then set equal to the dimension of array TER and index LIMP is set equal to the Y dimension of array PLT. Index ISCHEM, which deals with sophistication option in subroutine ADAPT (see A.2.11) is

Table A-1. A Summary of Subroutine Functions

No.	Subroutine	Primary Function	Group
1	IOLAB	Reads header card and writes it	Data read/write
2	IOLABD	Reads data in F format and writes it	
3	IOLAB2	Reads and writes header card with a line skip	
4	PROGIO	Coordinates data input and vehicle parameter printout	Data input
5	PROFILE	Reads terrain profile and processes it	
6	POINTC	Calculates tire forces for point contact model	Tire models
7	RTREAD	Filters profile for rigid tread band model	
8	FPRINT	Filters profile for fixed footprint model	
9	APRINT	Divides tire in sectors for adaptive footprint model	
10	ADORG	Coordinates tire force calculation for adaptive footprint model	
11	ADAPT	Calculates tire forces for adaptive footprint model	
12	SUSP	Calculates suspension forces	Vehicle model
13	BOGIE	Calculates bogie forces	
14	DYSYS	Coordinates dynamic simulation	Dynamic simulation
15	RKDIF	Coordinates Runge-Kutta integration algorithm	
16	STEQU	Provides derivatives of state variables	
17	PSTORE	Stores variables for plotting	Plotting
18	VPLOTS	Produces plots using CALCOMP subroutines	

normally set to 1*. Index LPHS is equal to 1, indicating, thereby, that subroutine PROFILE is called for the first time.

The main program calculates initial conditions for the dynamic simulation from geometric relationships. Then the simulation is carried out through subroutine DYSYS, and at the end of the simulation the main program terminates the run.

A.2.2 Subroutine PROFILE

Subroutine PROFILE reads the terrain elevation data from data cards and processes them according to the requirements of the tire model being used in the particular simulation run. The reading in of the data is accomplished in steps or "phases" in view of the limited core capacity used by the program. The size of the phases is determined by dimensions of arrays TER, OTER, DYX and ODYX which store various aspects of the terrain data. These arrays are dimensioned 500 so that program can fit in a reasonable amount of core space. If the terrain data has more than 500 points, the reading is temporarily halted at end of the first 500 points and the simulation is executed until it uses up the data already read. Then subroutine PROFILE is called again to read additional data and the process is repeated until the simulation is carried out over the complete profile. This phase simulation process is illustrated in Figure A-1 and described below.

Subroutine PROFILE is called initially from the main program, and subsequently it is called from the dynamic simulation routine DYSYS. When the subroutine is called for the first time, or indicated by LPHS, Part 1 is executed.

*ISCHEM is set to 2 if more accuracy is required. However, if a cost saving is desired while still employing the adaptive footprint model, ISCHEM is set to 0.

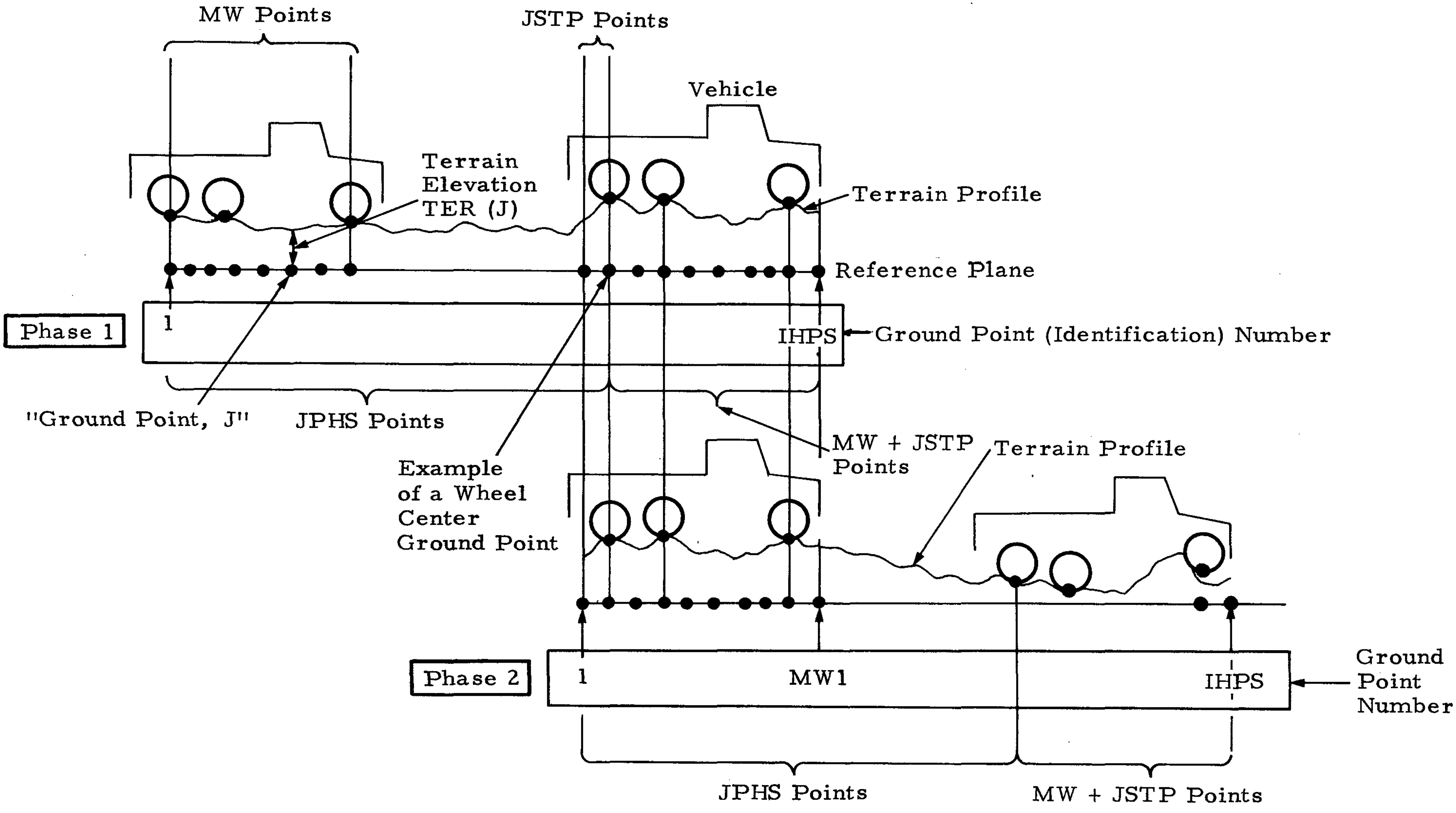


Figure A-1. Reading the Terrain Profile in Phases

<u>Part 1:</u> The following is accomplished in part 1.

a. Terrain parameters XDEL and JMAX are read.

b. The numbers of profile intervals between the rear and the front wheel centers (MW), and rear and the middle wheel centers (NW) are determined. The numbers are then adjusted to the nearest integers from the real numbers ((25)-(35)).*

c. Simulation parameter FTIME is determined from JFIN, which is the total number of terrain ground points minus the number of points under the truck. Incremental time (time step) DTIME is determined from the speed of the vehicle SPEED and the interval between the ground points XDEL. Finding DTIME this way ensures that the vehicle advances from ground point to ground point as the simulation progresses. The initial time is set to zero.

d. Adaptive footprint initialization subroutine APRINT is called if ITIRE is 4.

e. The three more sophisticated tire models (rigid tread band, fixed footprint and adaptive footprint) require knowledge of terrain elevation at JSTP ground points on either sides of the wheel center ground point. The value of JSTP is calculated thus ((45)-(51)):

JSTP = JL = Integer (CONL/2*XDEL) +1 for fixed footprint model

JSTP = JR = Integer (RAD/XDEL) +1 for rigid tread band and adaptive footprint models

JSTP = 0 for point contact model

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*Numbers in brackets refer to the corresponding line numbers on the left side of the listing (see A.4).

The value of JSTP is then used to set margines on the ends of a simulation phase.

f. Because the profile is read from data cards, the number of elevation points read in each simulation phase has to be an exact multiple of the number of data points on each card (say 8). This is ensured by ((54)-(59)).

g. The number of points to be skipped while storing the data for plotting (NXT) is determined from the starting and stopping values of the plot and size of the plot array ((61)-(62)).

h. The profile is read and then converted to a profile with correct RMS value ((67)-(69)) (see Note 1 in 2.2).

i. Index JPHS, which determines the number of steps the dynamic simulation is allowed to progress in a particular simulation phase, is calculated by (71). This value for JPHS ensures that at the end of the simulation phase, the front wheel center stops before the last data point, with JSTP margine left for computation (see Figure A-1).

Part 2: Part 2 is executed only when PROFILE is called subsequently from DYSYS. The major tasks of part 2 are:

a. The part of the profile under the vehicle is converted to the initial part of the next phase profile, because the rear part of the truck has not yet operated on it ((91)-(92)). This conversion establishes the first MW1 (=MW+1+2 JSTP) points of the next profile, as shown in Figure .

b. The value of ITEST, i.e., the terrain data points to be read in this phase, is adjusted so that it is divisible by the number of data points on each data card ((78)-(83)).

c. The value of IPHS, i.e., the total number of ground points in this phase, is adjusted so that the number of new profile data read in does not exceed the total data points left to be read (85).

d. New terrain data is read (94).

e. Finally a new value of JPHS, i.e., the number of steps the simulation is to progress in this phase, is determined ((98)-(99)).

Part 3: Part 3 is executed each time subroutine PROFILE is called, and it accomplishes the following tasks:

a. The terrain data are transferred to a new array, OTER, because array TER stores the filtered profile for the rigid tread band or the fixed footprint tire models ((103)-(104)).

b. Terrain slopes at each data point is determined by (109) and stored in arrays DYX and ODYX. Array DYX stores the filtered slopes in the next step.

c. If the rigid tread band tire model is being used, subroutine RTREAD is called. If the fixed footprint tire model is being used, subroutine FPRINT is called. These subroutines filter the terrain profile, and store new elevations in array TER and the slopes in array DYX.

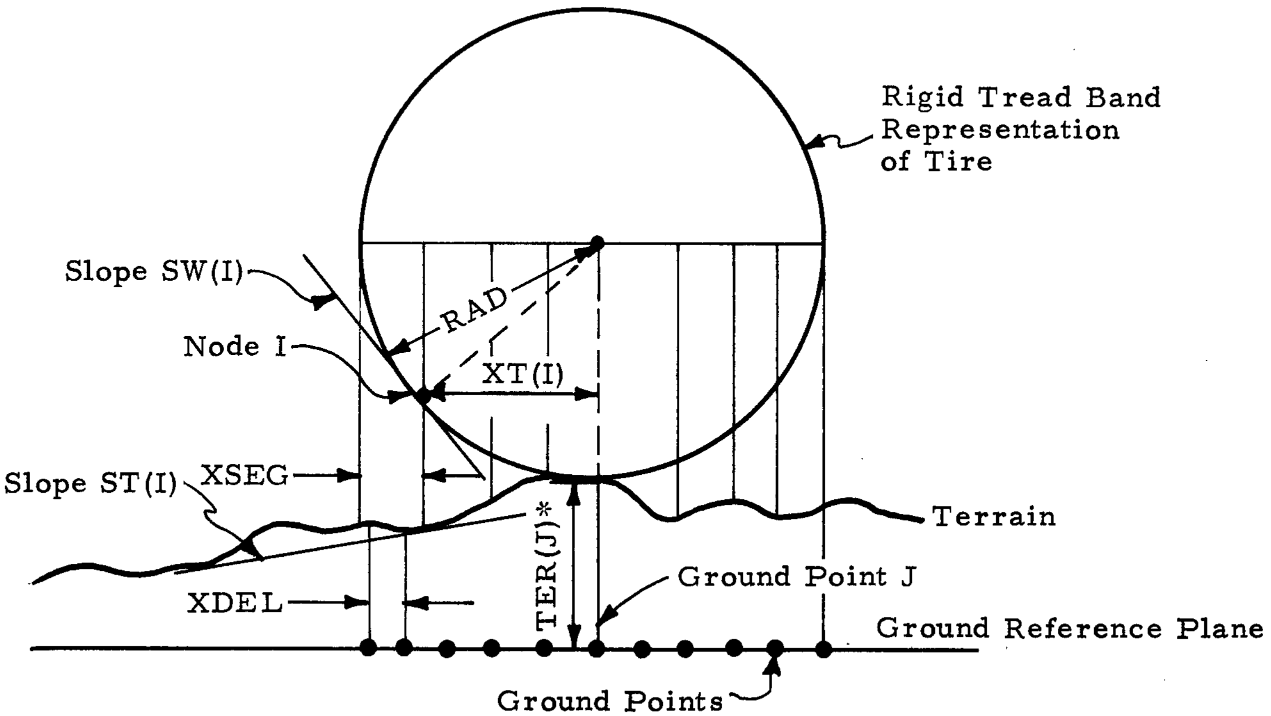
A.2.3 Subroutine RTREAD

Subroutine RTREAD filters the profile for the rigid tread band tire model. This task is accomplished by the following steps:

a. The diameter of the rigid tread band is divided in 2NS equal parts of length XSEG, with value of NS not less than 4, as shown in Figure A-2, ((11)-(15)).

In the Figure

NS = 4
JPT(I) = -4



*TER(J) Later Stores the Filtered Profile and OTER(J) Stores the Original Profile

Figure A-2. Parameters for the Rigid Tread Band Model

b. For each node on wheel periphery, similar to node I in the figure, distance from the wheel center vertical is calculated (18) and stored as XT(I).

c. Slope of the tire periphery for each node is calculated (21) and stored as SW(I).

d. For each node, the nearest groundpoint towards rear is determined and its serial number difference from the wheel center ground point (J) is calculated and stored as JPT(I) ((24)-(27)). The value of J is at least JR+1, so that the rear most ground point needed for calculation does not have an unknown elevation.

e. The slope of the terrain under node I, ST(I), is estimated by linear interpolation of the slope values of the surrounding ground points (37).

f. The difference between the terrain slope and the periphery slope is calculated and stored as G(I) (40).

g. The calculations e. and f. are repeated for all 2NS+1 nodes ((32)-(54)).

h. Index IS(I) is assigned value 0 for negative G(I) and value 1 for positive G(I) ((42)-(44)).

i. If the sign of G(I) changes from positive to negative going from node I-1 to node I, a contact point may exist between the two nodes. For all such cases, distances of the possible contact points from the wheel center vertical, XC(K), are determined by linear interpolation (52).

j. The terrain slopes at the possible contact points are also determined from linear interpolation and stored as DYC(K) (53).

k. Terrain elevations at the possible contact points are found by linear interpolation from the nearest ground point on the rear and stored in array TPT (61).

l. Elevation of the wheel center for each possible contact point is found and stored as YTER(I), for I = 1, K (62).

m. The largest value of YTER(I), from the values calculated in the previous step, is the actual wheel center elevation and the corresponding contact point slope is DYC(I). The values of YTER(I) and DYC(I) thus found are transferred to arrays TER(J) and DYX(J) respectively ((67)-(72)). These values represent the filtered terrain profile elevation (plus a radius bias) and the filtered profile slope corresponding to the ground point J.

n. The steps e. to m. are repeated for ground points from JR+1 to IPHS-JR ((30)-(74)).

o. The elevations for the ground points 1 to JR and IPHS-JR+1 to IPHS are assumed to be equal to those for ground points JR+1 and IPHS-JR respectively. The corresponding slopes are assumed to be zero ((74)-(81)).

p. Finally the radius bias is removed from the entire filtered profile ((83)-(84)).

A.2.4 Subroutine FPRINT

The profile is filtered for the fixed footprint model by subroutine FPRINT. This is accomplished by determining averages of the terrain elevation and the terrain slope under footprint of the tire.

To initiate the filtering process, indices JL and MFF are calculated from size of the footprint length CONL. The limits for the calculation are set from ground point number JL+1 to number IPHS-JL so that there are enough margins left when the averages at the end points of a terrain data record are calculated. Averages for terrain elevation and slopes are then obtained by adding the ground point elevations and slopes under the tire footprint and dividing the sums by the total number of ground points under the footprint - MFF ((13)-(22)). The averages thus obtained are stored in arrays TER and DYX. Also, just as for the rigid tread band model, the filtered elevations for the ground points 1 to JL and IPHS-JL+1 to IPHS are assumed to be equal to those for points JL+1 and IPHS-JL respectively. The slopes for these groundpoints are assumed to be zero ((23)-(29)).

A.2.5 Subroutine APRINT

When the adaptive footprint tire model is being used, subroutine APRINT is called from subroutine PROFILE to divide the wheel into pie shaped sectors and to calculate various parameters associated with the sectors. In dividing the wheel into sectors, only a part of the wheel most likely to be in contact with the ground (say ±30° from the vertical) is considered. The number of divisions are selected to be 19 (=NAD2) and the size of each sector then is 60°/19 = 3.15°. The sectors are arranged so that the center line of the middle sector is vertical.

For each of the NAD2 sectors, sector angle ADTH(I), i.e., the angle made by the sector center line with the vertical, is calculated (see Figure A-3). Other parameters calculated are sine of the angle (ADST(I)), cosine of the angle (ADCT(I)), tangent of the angle (ADTT(I)), number of ground points in the sector center line projection (NSG(I)) and ADDX(I) (shown in Figure A-3). These parameters are constants and therefore they are not recalculated during the simulation.

A.2.6 Subroutine DYSYS

The dynamic simulation part of the program is coordinated by subroutine DYSYS. Dynamic simulation includes integrating the differential equations describing the vehicle behavior (state equations) and providing the results in appropriate form to various output devices. To perform integration, DYSYS calls subroutine RKDIF (described in A.2.7) which incorporates a fourth order Runge-Kutta numerical integration scheme. The differential equations needed for integration are, however, stored in subroutine STEQU, which is called four times every time step by RKDIF to obtain updated values of the derivatives of the variables. As the integration progresses, the results are supplied to:

a. The printer (after every MM time steps)

b. Subroutine PSTORE, which stores values of the variables to be plotted. (The plots are later produced by subroutine VPLOTS called at the end by DYSYS.)

c. The card punch, to prepare records of the axle displacements.

Selected variables can also be stored on magnetic tape by adding a few cards as described in A. 3. These variables can then be processed by program SPEC.

With this introduction, the individual steps in the subroutine are explained in the following

a. Equilibrium deflections of the tires (YST2, YST3, and YST4) and the suspensions (YSP2, YSP3, and YSP4) are determined in ((29)-(38)) if any of the first three tire models are being used. If the adaptive tire model is being used the procedure is as follows:

(1) Initial height of the tire center, Y1, is selected to be equal to two times the radius plus the terrain elevation under the tire center (TER(JGR)). (See Figure A-3.)

(2) Subroutine ADAPT is called to determine the vertical force, FYY, on the tire.

(3) The vertical force is compared with the equilibrium weight on the tire, i.e., WTR2, WTR3 or WTR4, depending on the position of the tire in the vehicle.

(4) If FYY is less than the weight, the tire center is moved down by 0.3 inches and the procedure is repeated from (2).

(5) If FYY is more than the weight, the tire center is moved up by 0.3 inches.

(6) Subroutine ADAPT is called to determine FYY.

(7) If FYY is less than the equilibrium weight, the tire center is moved down by 0.03 inches and the step (6) is repeated.

(8) If FYY is more than the equilibrium weight, the wheel center height is stored as YI12, YI13 or YI14 depending on whether the tire is in front, middle or rear of the vehicle.

b. System subroutine SECOND is called (before and after the simulation) to determine the wall clock time required to execute the simulation.

c. Subroutine STEQU is called to initialize derivatives of the state variables and other variables involved in the state equations (such as forces on the vehicle). These initial values are then printed in the simulation output. If the user requires plots of the variables starting from the equilibrium values, subroutine PSTORE is also called ((75)-(134)).

d. Subroutine RKDIF is called to numerically integrate the state variables and generate values of the variables at the next time step (137).

e. The variables are printed (after every MM time steps) ((126)-(131)). The selected variables are also stored for plotting ((160)-(169)).

f. The values of time (TIME) and axle displacements (YW2, YW3 and YW4) are stored on an intermediate tape (TAPE 8) and punched ((122) and ((179)-(191))). The intermediate tape is used so that more than one set of data can be stored on each card. (The data on these cards can later be transferred to another mass storage medium, such as paper tape or magnetic disc.)

g. Steps d. to f. are repeated for every time step until the vehicle reaches the end of the section of the profile already read (i.e., end of a phase of the simulation is reached).

h. Subroutine PROFILE is called to read additional profile data ((153)-(155)).

i. Steps d. to h. are repeated until end of the profile is reached, as indicated by TIME $\geq$ FTIME (100).

j. If plots are requested, the plotting subroutines are initiated by calling INITPLT. The origin is fixed by calling PLOT two times and subroutine VPLOTS is called to generate the plots. The plotting is terminated by calling FIN.

A.2.7 Subroutine RKDIF

RKDIF is a numerical integration subroutine which calculates the values of the state variables at time t+dt, given the values at time t, using a 4th order Runge-Kutta method. The integration scheme is summarized below.

a. The iteration procedure starts with the values of the state variables y_1, y_2, etc., at time t.

$$y_i(t) \quad i = 1, n$$

b. The slopes $Dy_i(t)$ are then determined from $y_i(t)$ by calling STEQU.

$$Dy_i(t) = dy_i(t)/dt$$

c. The values y_{i1} at time $t + \frac{dt}{2}$ are then determined,

$$y_{i1} = y_i + Dy_i \cdot dt/2$$

d. The slopes $Dy_{i1}(t + dt/2)$ are then determined by calling STEQU and using the values of y_{i1} found in c. above.

e. The values y_{i2} at time $t + dt/2$ are then determined

$$y_{i2} = y_i + Dy_{i1} \cdot dt/2$$

f. The slopes Dy_{i2} $(t + dt/2)$ are then determined from STEQU using the values of y_{i2} found in e. above.

g. The values y_{i3} at time $t + dt$ are then determined

$$y_{i3} = y_i + D_{yi2} \cdot dt$$

h. The slopes Dy_{i3} at time $t + dt$ are then determined from STEQU using the values of y_{i3} found in g. above.

i. Finally, the values of the state variables at time $t + dt$ are found as follows

$$y_i(t\ dt) = y_i(t) + (Dy_i + 2Dy_{i1} + 2Dy_{i2} + Dy_{i3})\ dt/6$$

A.2.8 Subroutine STEQU

This subroutine incorporates the differential equations describing the vehicle motion (state equations) in terms of the state variables and forces on the vehicle components. In order to update values of the derivatives, subroutine STEQU obtains the current values of the state variables from subroutine RKDIF. From these values, forces acting on the tires, suspensions bogie and hull are obtained by calling subroutines POINTC (for the first three tire models), ADORG (for the adaptive footprint model), SUSP and BOGIE. The derivatives of the state variables are then obtained from the state equations (i.e., equation 1, 2, 4, 39, 41 and 43 in Appendix B of reference 1). The accelerations are calculated directly from the derivatives of the state variables, with the exception of the bogie heave acceleration which is obtained from equation 7 in Appendix B of reference 1.

A.2.9 Subroutine POINTC

Subroutine POINTC determines the vertical and horizontal forces acting on each tire using the point contact tire model. For the rigid tread band model (or the fixed footprint model) the profile is first filtered by subroutine RTREAD (or FPRINT) and then the filtered profile is used to obtain the forces from subroutine POINTC. The task is performed by the following steps:

a. Terrain elevation and time rate of change of elevation under each tire is determined ((20)-(25)). In these equations index KPHS represents the ground point under the rear wheel center. Adding NW and MW to KPHS gives ground points under the middle and the front tires respectively.

b. The vertical forces on the tires are determined from the point contact model equations (see reference 1, Appendix A) ((28)-(44)). Equilibrium tire deflections YST2, YST3 and YST4 used in the equations are precalculated in subroutine DYSYS.

c. The horizontal forces on the tires are obtained by multiplying the vertical forces by the appropriate profile slopes ((47)-(49)).

A.2.10 Subroutine ADORG

This subroutine coordinates calculations of the vertical and horizontal tire forces for the adaptive footprint tire model. The force calculations are actually carried out by subroutine ADAPT, but they are in terms of general displacement, velocity and force variables. These general variables are converted, in subroutine ADORG, to specific variables for the front, middle and the rear tires, as summarized in Table A-2. Of these variables, Yl (elevation of the wheel center from the ground reference plane, see Figure A-3), JGR (ground point under the wheel center) and DYW (heave velocity of the wheel center) are needed by subroutine ADAPT to carry out the force calculations. Therefore, subroutine ADORG assigns these general variable names to the specific variables for the front, middle and rear tires. Subroutine ADAPT is called next, for each of the three tire positions and the resulting general force variables, FXX and FYY are converted to specific variable according to Table A-2.

Table A-2. Conversion of General Tire Variables to Specific Variables

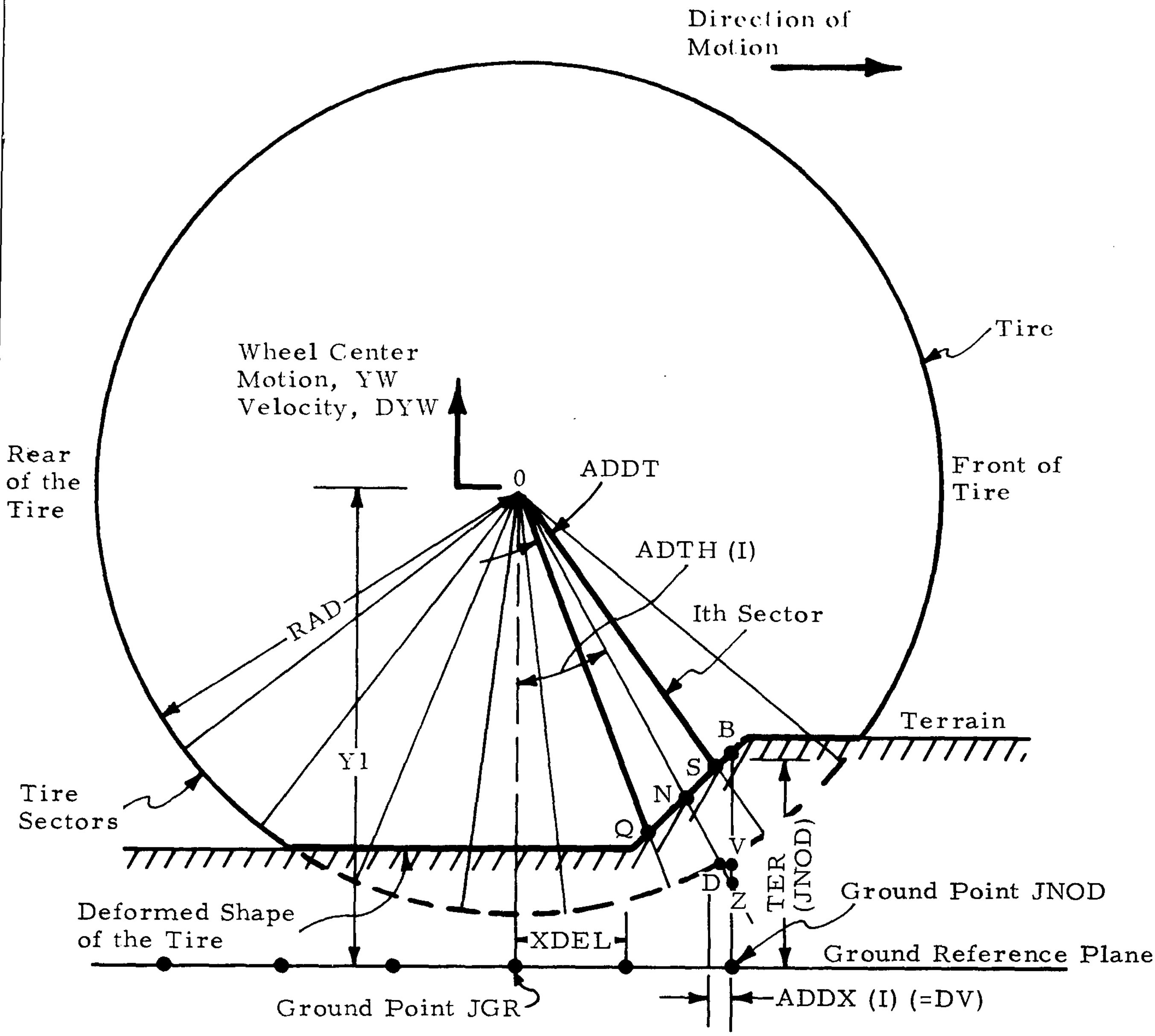
General Variables	Specific Variables		
	Front Tires	Middle Tires	Rear Tires
FYY	FV2	FV3/2*	FV4/2*
FXX	FH2	FH3/2*	FH4/2*
YW	YW2	YW3	YW4
DYW	DYW2	DYW3	DYW4
YI1	YI12	YI13	YI14
JGR	KPHS+MW	KPHS+NW	KPHS

*Forces FV3, FV4, FH3 and FH4 are for tire pairs.

A.2.11 Subroutine ADAPT

Subroutine ADAPT determines the horizontal and the vertical forces acting on tires, using the adaptive footprint tire model. There are two parts to the calculations:

a. Geometric calculations
b. Force calculations



DELTA(I) = BV
DELR(I) = DN
AL1(I) = SN
AL2(I) = QN
AL(I) = QS
Periphery Point is D

Initial Value of Y1 is YI1

Figure A-3. Sector Calculations for the Adaptive Footprint Model

The geometric calculations deal with obtaining radial deflections and contact lengths for the tire sectors in contact with the ground. The force calculations use the geometric parameters thus determined to obtain various force components for the tire sectors and then the total horizontal and vertical forces at the tire center.

Before commencing the calculations, the storage arrays are cleared and index IBACK is set to zero. Setting IBACK to zero indicates that the calculations will start from the bottom sector (I=1) and progress towards the front of the tire (see Figure A-3). After all the sectors in contact with the ground are considered, IBACK is set to 1 and the calculations proceed along the rear of the tire.

Part 1 - Geometric Calculations ((47)-(109)) - There are three choices of accuracy available to the user in the geometric calculations. The choice is indicated by selecting a value of ISCHEM. For ISCHEM=0, an algorithm with low accuracy is used, where as ISCHEM=2 indicates choice of an accurate but expensive algorithm. Normally ISCHEM=1 is used, which means that an algorithm with an in between accuracy and cost will be used.

ISCHEM=0: The geometric relations used in obtaining the radial deflection, DELR(I), and the contact length, AL(I) (see Figure A-3), for sector I are approximate.

DELR(I) = DELTA(I)* ADCT
AL(I) = (RAD- DELR(I))* ADDT

These calculations also presume that the ground contact is continuous and includes the bottom point of the tire.

ISCHEM=1: More complex and accurate relations are used in determining the radial deflections and the contact lengths of the tire sectors. The accuracy is also improved by including, in the contact length calculations, the sectors which are only partly in ground contact. However, it is still assumed that the ground contact is continuous and includes the bottom point of the tire.

ISCHEM=2: This scheme is identical in all respects to the above scheme, except that the ground contact may now be discontinuous and may not include the bottom point of the tire.

The steps involved in the geometric calculations are then summarized in the following:

a. Sector number I is set to 1 (bottom sector).

b. Ground point number corresponding to each sector is determined and stored as JNOD.

c. Slope of the profile under the sector is determined from the stored data ((50)-(52)). If the sector is on the forward side, the slope is calculated corresponding a ground point ahead of the sector ground point to improve accuracy.

d. Vertical deflection DELTA(I) is calculated (55) from the geometric relations between the variables shown in Figure A-3.

e. Radial rate of deformation of the sector, DDEL(I) is determined by subtracting the radial velocities of the two ends of the sector (56).

f. If ISCHEM=0, the radial deflection and the contact length are found from the approximate model ((78)-(81)) and the calculations are moved to step l. For this approximate model, APHI(I) is considered to be equal to ADTH(I), and the sector is considered to be out of ground contact if DELR(I) is negative (see step p.).

g. For any of the following conditions, the accurate geometric calculation algorithms tend to become unstable and therefore the calculations are performed according to the approximate model.

(1) $||APHI(I) - ADTH(I)| - \pi/2| < 0{\cdot}1$ (radian)

(2) $||APHI(I) - ADTH(I) + ADDT/2| - \pi/2| < 0{\cdot}1$

(3) $||APHI(I) - ADTH(I) - ADDT/2| - \pi/2| < 0{\cdot}1$

h. For I=1, i.e., the bottom sector, DELR(I) is equal to DELTA(I) (61). For I≠1, DELR(I) is ND in Figure A-3 and it is determined by geometric relationships in triangles BNZ and DVZ (63).

i. If DELR(I) is positive, IDAMP(I) is set to 1 so that the sector will be considered in damping force calculations. If DELR(I) is negative, the sector is considered for partial contact, as described in step m. If DELR(I) is more than the radius of the tire, the accurate algorithm is considered unstable and the approximate algorithm described in step f. is used.

j. The contact lengths AL1(I) and AL2(I) (i.e., SN and QN in Figure A-3) are determined from geometric relationships in triangle OQS ((70)-(71)). If either AL1(I) or AL2(I) is more than DELR(I), the sector is considered to be in partial contact as described in step m.

k. The contact length AL(I) is found by adding AL1(I) and AL2(I).

l. The value of I is incremented by 1, and if I is less than the total number of sector, NAD2, the procedure is repeated from step b.

m. The sectors which have exhibited:

(1) DELR(I) negative
(2) Either AL1(I) or AL2(I) less than DELR(I)

are considered for partial contact ((97)-(109)). For determining the partial contact lengths, difference between APHI(I) and ADTH(I) is stored as DIFPT.

n. If DIFPT is negative and (1) DELR(I) is negative, the sector is considered out of ground contact and process moves to step p. (2) DELR(I) is positive, the sector is considered to be in full contact and the process moves to step k.

o. Terms ZHS and YHS are determined from the geometric relations shown in Figure A-4. If ZHS > YHS, the sector is considered to be completely in ground contact and the process moves to step k. Otherwise, AL(I) is found by adding ZHS and YHS and dividing the sum by Cos (DIFPT). If AL(I) is found to be negative, the sector is considered out of ground contact and the process moves to step p.

p. If there is no sector-ground contact, DELR(I) and AL(I) are set to zero. In case of ISCHEM=0 or 1, no sector-ground contact means that there is no more contact in front of the tire and the calculations are

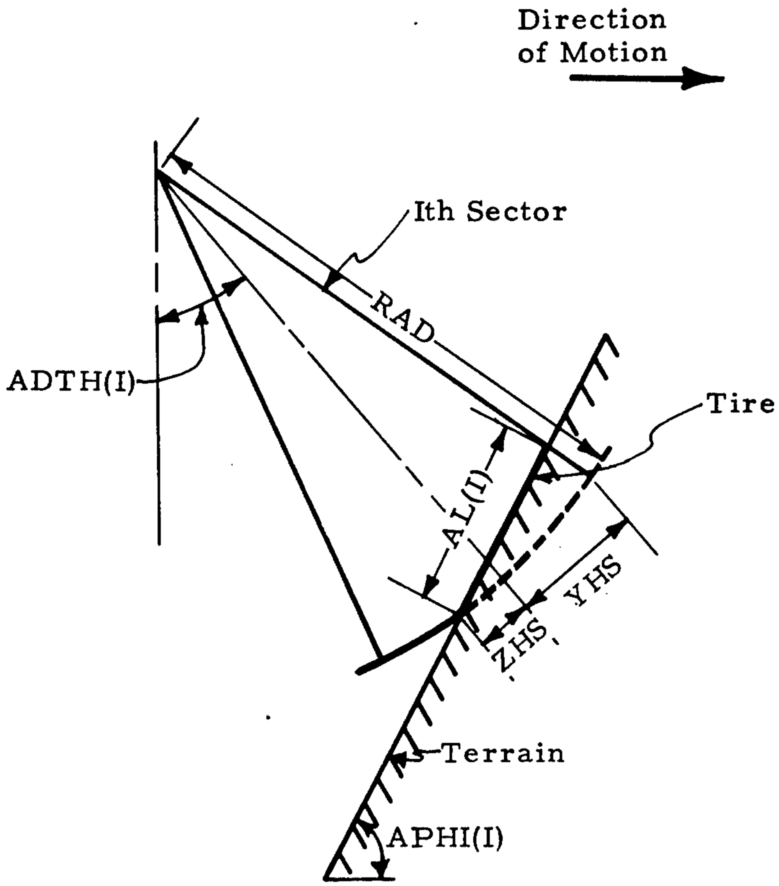


Figure A-4. Tire Sector in Partial Contact repeated for the rear sectors (I=NBACK) by starting from step b. ((93)-(94)). If, however, the rear sectors have also been considered, as indicated by IBACK=1 (91), the calculations for Part 1 are completed and Part 2 is executed as described below.

For ISCHEM=2, no such end of contact is assumed and all the sectors are considered for possible multiple contacts. Therefore, the process is transferred to step 1.

Part 2 - Force Calculations ((113)-(131)) - After the geometric calculations are completed, Part 2 of the subroutine is executed. The force calculations considered in Part 2 involve determining the pressure, stiffness and damping forces for each sector, finding their components perpendicular and horizontal to the ground, eliminating the negative perpendicular forces and finally determining the inertial vertical and horizontal forces (FYY and FXX in Figure A-5). The steps in detail are:

a. Forces FXX, FYY and contact length TLENT are set initially to zero. These parameters are determined by performing addition of the force components and the sector contact lengths using a DO loop ((116)-(131)).

b. Pressure force for a particular sector, FP(I) (see Figure A-5) is determined by multiplying the tire pressure to the sector contact area (118).

c. Carcass stiffness force, FKT(I), is determined by integrating the incremental stiffness force along the radial deflection (121).

d. Damping force, FBT(I) is determined from the distributed damping constant ABC and the rate of sector deformation calculated in step e. of Part 1. If the sector is not in the ground contact, IDAMP(I), and subsequently FBT(I), are zero (125).

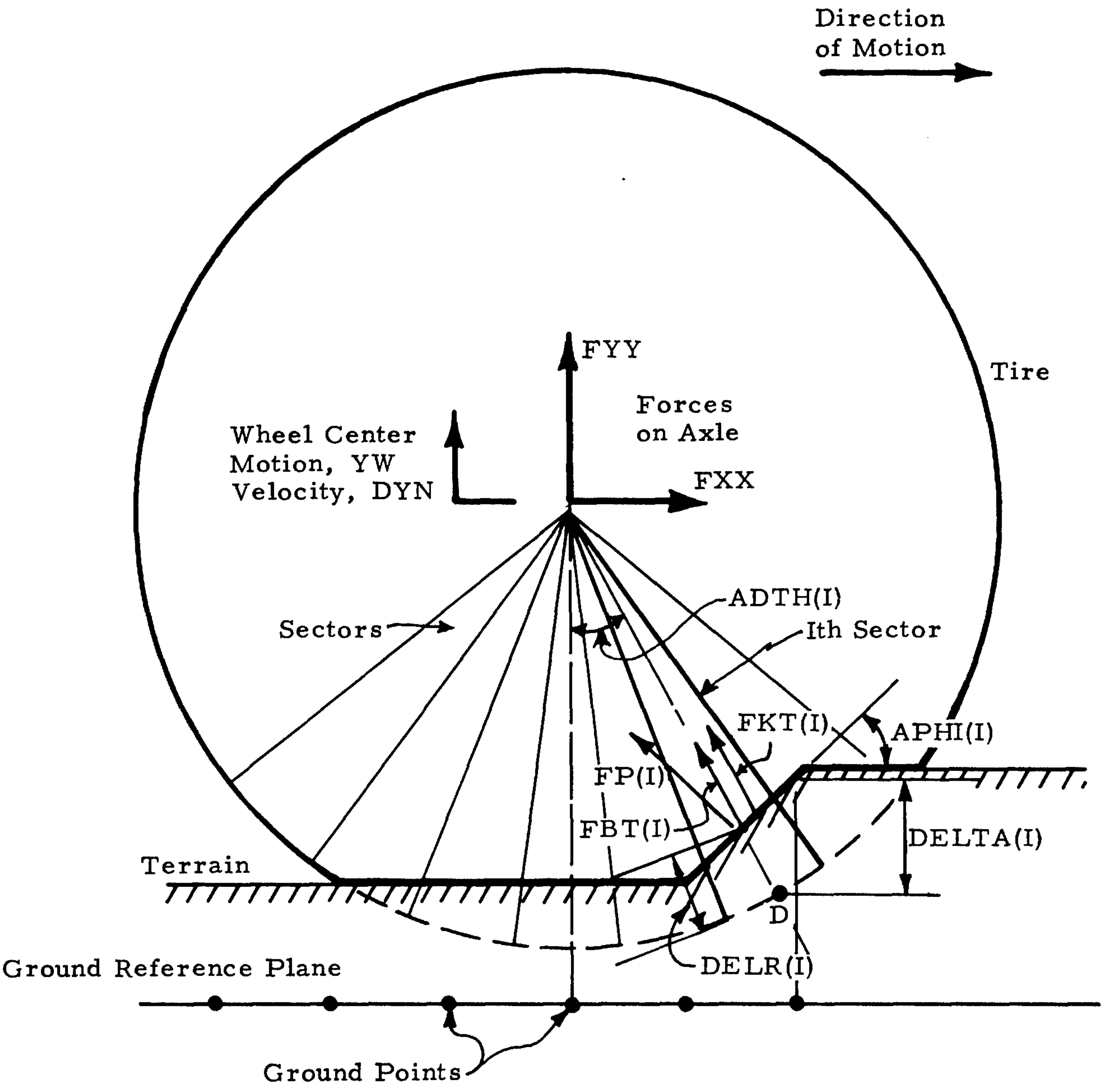


Figure A-5. Tire Forces in the Adaptive Footprint Model

e. Total sector force normal to the ground, FNG(I), is found by adding the components of the pressure, stiffness and damping forces. Since only the compressive forces can be transmitted between the tire sector and the ground, FNG(I)=0, if FNG(I)$\leq$0.

f. Total sector force horizontal to the ground, FHG(I), is found similarly.

g. Vertical sector force is found from components of the forces vertical and horizontal to the ground. The sector forces are added to give FYY.

h. Horizontal sector forces similarly give FXX.

The end products of Part 2, and that of the subroutine, are the vertical force, FYY, and the horizontal force, FXX, exerted by the tire on the axle.

A.2.12 Subroutine SUSP

Subroutine SUSP calculates the forces in the suspensions according to the following steps:

a. Displacements and velocities of both ends of the suspensions are required to calculate the forces. Those for the bottom ends are available directly from the state variables YW2, YW3, YW4 and DYW2, DYW3, DYW4. The displacements and velocities for the top ends are calculated from equations 13, 16, 23, 24, 27, 28, 34 and 37 in Appendix B of reference 1.

b. Leaf spring stiffness forces are calculated from equations 10, 11, 20, 21, 31 and 32 of the reference report and leaf spring dry friction forces are calculated from equations 14, 15, 25, 26, 35 and 36. It should be noted that the dry friction factor, FRSF, is assumed to be 0.05, which means that the dry friction force is 5 percent of the instantaneous sprint force and opposes the velocity.

c. Stop contact forces are calculated from equations 18, 29 and 38.

d. Viscous damper force for the front suspension is calculated from equation 17.

e. Finally the forces are added to give the total suspension forces according to equations 9, 19 and 30. The horizontal forces are obtained from equations 40, 42 and 44.

A.2.13 Subroutine BOGIE

Subroutine BOGIE calculates the frame stop forces and the forces acting on the bogie.

a. The stop forces, determined from equations 45, 46, 47, and 48, are assumed to act on the unsprung masses. This is so because the bogie in the model represents just the inertial properties of the suspension springs. The stiffness and the damping properties of the spring are represented by the middle and the rear suspensions. The stop forces act on the ends of the spring and therefore on the unsprung masses at the other ends of the suspensions in the model.

b. The horizontal and the vertical forces transmitted by the bogie to the hull are calculated using equations 5 and 8, respectively.

A.2.14 Subroutine VPLOTS

Subroutine VPLOTS includes the CALCOMP plotting subroutines, which are executed to produce plots of the variables stored by subroutine PSTORE in array PLT. The data for the Y axis of the plots are obtained from PLT (IPLN, I), where IPLN is the number of the plot. These data are transferred to array A(I) in subroutine VPLOTS. Similarly the X axis data stored in PLT(9, I) are transferred to array B(I). Number YPN, which represents the particular variable being plotted according to the list in Table 3, is written on the Y axis of the plot.

The rest of the subroutine consists of calling the standard CALCOMP subroutines SCALE, AXIS, NUMBER, LINE and PLOT.

A.2.15 PSTORE

Subroutine PSTORE stores the variables to be plotted, which are selected by the user by punching 1 in appropriate columns of card No. 56 (see 2.2). The column numbers correspond to the variable numbers in Table 3, and are stored in array NPLT(J), J=1, NPLTM, where NPLTM is the total number of plots desired.

When PSTORE is called, the system variables available for plotting are converted to an appropriate member in array YPLT(M), where M corresponds to the variable number in Table 3. Then if the Mth variable is to be plotted, YPLT(M) is converted to PLT(J,IXT) where J=1, NPLTM and IXT is the plot point number supplied by DYSYS.

Simultaneously X axis data are stored in array PLT (9, IXT). The X axis can either be XREAR (the X coordinate of rear wheel center) or TIME. The user makes the selection by punching appropriately in column 41 of card 56, and thereby setting the value of IXAX.

A.3 Associated Programs

The programs described in this appendix can be used in conjunction with the vehicle simulation program as described in Figure 3. Program GRND can be used to generate a profile if such data are not available, whereas, program SPEC can be employed to determine spectral densities of various variables associated with the simulation.

A.3.1 Program GRND

A.3.1.1 Description

This program generates a ground profile in terms of elevations at specific intervals. The spectral density of the generated profile is given by

$$S_{y_0}(\Omega) = A/\Omega^2; \frac{2\pi}{\lambda_1} < \Omega < \frac{2\pi}{\lambda_2}$$

$$= 0 \text{ elsewhere}$$

where Ω is a reduced frequency given by:

$$\Omega = \omega/V = 2\pi/\lambda$$

and λ_1 and λ_2 are cut-off wavelengths, selected to be λ_1 = 57 feet and λ_2 = 2 inches.

From the definition of power spectral density

$$\overline{y_0}^2 = \int_{\infty}^{\infty} S_{y_0}(\Omega)\, d\Omega$$

The details of the computation required to generate the profile is available in Appendix C of reference 2 and therefore it is not repeated here.

The parameters XX, XX1, XX2, YY, YY1 and YY2 in the program are random numbers, selected from random number tables. These random numbers are used to obtain PHI(K) ($=\phi_k$ in reference 2) and THETA(K) ($=\delta\Omega_k \cdot 20/(\Omega_k \cdot \Delta\Omega_k)$). The discrete reduced frequencies Ω_k are calculated such that the log scale from $\Omega_1 = 0.11$ to $\Omega_{150} = 35.4$ is divided equally in 149 parts. For each frequency, Ω_k, the profile spectral density (A/Ω_k^2) is determined and stored as S(K).

Subroutine EVALFN is called for each of the 5000 ground points to calculate terrain elevation using the 150 discrete frequencies obtained earlier. The calculated elevations are punched on data cards in an 8E10·3 format. The mean square value of the profile (SIGMA2) is calculated by numerical integration and it is printed to help confirm validity of the generated profile. Also printed are the total number of elevation values which lie in each of the 40 bands of elevation magnitude, spread between -2σ (σ = RMS value of the profile $= \sqrt{\overline{y_o^2}}$) to $+2\sigma$. This table is useful in determining probability distribution of the profile.

A.3.1.2 Inputs

There are essentially only two inputs to the program, assuming that the profile spectral density shape is not changed.

a. XDEL, i.e., the interval at which the elevations are determined. It is selected to be 0.1 foot.

b. A, i.e., the ground roughness parameter. It is selected as 0.1105, so that the RMS value of the profile elevation is 1 foot. Since the terrain-tire-vehicle simulation program converts the generated profile to a profile with the user selected RMS value, the value of A used in the profile generation program may not be changed.

A.3.1.3 Outputs

The following are the program outputs.

a. A deck of cards with the terrain elevation coordinates in 8E10.3 format.

b. Mean square value of the profile elevation.

c. The distribution of profile elevation (G(M)).

A.3.1.4 Listing

Printed on the following pages.

```
      PROGRAM GRND(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,PUNCH)
C PROGRAM TO GENERATE TERRAIN PROFILE
      COMMON PHI(150),THETA(150),OMEGA(150),OMEGAP(150),S1(150),S(150)
      DIMENSION XX(50),YY(50),XX1(50),YY1(50),XX2(50),YY2(50)
      DIMENSION G(40),GMF(40)
      DIMENSION F(5000),DFDX(5000)
      DATA XX/6.25,4.93,4.96,4.40,2.53,0.81,5.21,3.00,0.15,4.94,0.11,
     1 2.34,5.18,5.91,5.81,3.58,4.65,5.00,4.57,4.08,0.59,5.55,1.90,
     2 2.81,4.41,6.16,0.48,3.24,3.99,5.56,5.68,0.23,2.71,3.62,3.40,
     3 3.20,5.70,6.06,1.50,4.88,6.00,1.25,1.79,3.15,2.08,0.82,2.63,
     4 5.39,4.61,2.21/,
     5YY/-.53,0.50,-.47,0.79,-.42,0.05,-.31,0.94,-.60,.35,-.29,-.23,
     5 .21,.53,.22,.49,.30,-.75,.73,.56,-.55,-.46,
     1 -.05,-.14,.64,.57,.19,.67,.28,-.73,.41,.73,.25,.68,-.94,
     2 -.05,.50,.21,-.75,.48,-.92,.97,.52,.44,-.32,-.46,.78,.86,
     2 -.10,.29/
      DATA XX1/3.66,2.78,5.37,4.21,5.93,2.63,4.96,1.11,0.81,
     4 5.94,5.71,3.60,4.80,5.15,6.10,4.38,4.43,5.08,3.53,1.42,
     5 4.36,5.18,2.81,4.32,4.65,2.00,2.69,0.07,4.15,3.12,3.32,1.24,
     5 1.13,2.59,1.37,1.28,3.60,3.90,0.03,3.84,2.64,5.45,
     6 5.66,5.82,1.44,2.22,5.60,2.26,1.22,1.29/,
     1YY1/-.80,.66,-.21,.02,-.66,-.19,-.01,.43,-.27,.29,-.22,-.39,
     2 .88,.74,-.09,.33,.97,.89,-.60,-.77,-.84,.48,.05,.63,-.31,.81,
     3 .39,.63,.98,-.59,.45,-.34,.83,.70,-.55,.51,.86,.85,.89,-.39,
     4 -.01,.13,.41,.87,-.42,.76,.36,-.53,.53,.47/,
     1XX2/1.04,2.23,2.41,4.21,3.75,2.89,.94,1.03,.71,5.10,.23,.10,5.21,
     2 .70,4.86,5.41,3.26,2.93,.24,2.96,.07,.53,.05,2.59,.97,1.79,4.65,
     3 1.45,3.49,5.39,.89,1.56,1.50,4.65,4.83,3.99,.69,1.43,3.68,4.09,
     5 6.11,1.27,2.13,5.40,5.39,5.84,3.23,2.70,3.30,2.05/,
     1YY2/.51,.86,.85,.39,-.39,-.01,.13,.41,.87,-.42,.76,.36,-.53,-.47,
     2 .47,-.14,-.19,-.85,-.89,-.41,.80,-.52,-.77,.50,.25,.79,-.18,
     3 -.34,-.31,.26,-.80,.54,.43,.72,-.92,.41,.84,.64,-.85,.22,
     4 .70,.03,.33,.96,.91,-.31,.14,-.81,.77,.95/
C***DATA
      XDEL=0.1
      A=0.1105
C********
      DO 11 I=1,50
      I1=I+50
      I2=I+100
      PHI(I)=XX(I)
      PHI(I1)=XX1(I)
      PHI(I2)=XX2(I)
      THETA(I)=YY(I)
      THETA(I1)=YY1(I)
      THETA(I2)=YY2(I)
   11 CONTINUE
      EL3=1./36.
      OMG1=(2.**EL3-1./(2.**EL3))
      EL=19./36.
      OMG1=0.078125*(2.**EL)
      DO 3 K=1,150
      AK=K
      EL2=(AK-1.)/18.
      OMEGA(K)=OMG1*(2.**EL2)
      OMEGAP(K)=OMEGA(K)*(1.+THETA(K)*OMG1/20.)
      S(K)=A/(OMEGA(K)**2)
```

```
      S1(K)=(2.*S(K)*DMG1*OMEGA(K))**.5
    5 CONTINUE
      DO 2 MM=1,5000
      M=MM-1
      X=XDEL*M
      CALL EVALFN(F(MM),DFDX(MM),X)
    2 CONTINUE
      PUNCH 17,(F(II),II=1,5000)
   17 FORMAT(8E10.3)
      SIGMA2=0.
      DO 15 K=1,150
   15 SIGMA2=SIGMA2+S(K)*DMG1*OMEGA(K)
      WRITE(6,32) SIGMA2
   32 FORMAT(F15.8)
      SIGMA=SQRT(SIGMA2)
      DELTA=SIGMA/10.
      DO 90 M=1,40
      G(M)=0.
   90 CONTINUE
      DO 100 M=1,40
      UPBND=-2.*SIGMA+M*DELTA
      BNDLOW=-2.*SIGMA+(M-1)*DELTA
      DO 100 I=1,5000
      IF(F(I).LT.BNDLOW)GO TO 100
      IF(F(I).GE.UPBND)GO TO 100
      G(M)=G(M)+1
  100 CONTINUE
      WRITE(6,56)
   56 FORMAT(*            G(M)*)
      DO 110 M=1,40
      WRITE(6,55)M,G(M)
   55 FORMAT(I6,F15.8)
  110 CONTINUE
      END
```

```
      SUBROUTINE EVALFN(FF,DFF,X)
      COMMON PHI(150),THETA(150),OMEGA(150),OMEGAP(150),S1(150)
      FF:0.
      DFF=0.
      DO 1 K=1,150
      FF=FF+S1(K)*(COS(OMEGAP(K)*X+PHI(K)))
      DFF:DFF-S1(K)*OMEGAP(K)*(SIN(OMEGAP(K)*X+PHI(K)))
    1 CONTINUE
      RETURN
      END
```

Output

.99703103

	G(M)
1	33.00000000
2	35.00000000
3	51.00000000
4	77.00000000
5	74.00000000
6	64.00000000
7	97.00000000
8	102.00000000
9	108.00000000
10	121.00000000
11	137.00000000
12	137.00000000
13	171.00000000
14	173.00000000
15	[illegible]
16	[illegible]
17	156.00000000
18	159.00000000
19	146.00000000
20	130.00000000
21	144.00000000
22	159.00000000
23	157.00000000
24	127.00000000
25	128.00000000
26	114.00000000
27	105.00000000
28	109.00000000
29	137.00000000
30	136.00000000
31	129.00000000
32	121.00000000
33	122.00000000
34	113.00000000
35	121.00000000
36	110.00000000
37	111.00000000
38	76.00000000
39	48.00000000
40	50.00000000

A.3.2 Program SPEC

A.3.2.1 Description

Program SPEC employs a fast fourier transform algorithm to generate spectral densities of different variables from their time histories, which are stored on a magnetic tape during execution of the vehicle simulation program (see Section A.3.2.2 for details). These time histories are read from the tape and stored in array F(I). These data are processed in the following ways before determining the spectral densities:

a. The number of discrete values in each time history is reduced to 4096, because it is more convenient to process 2^N points using the fast fourier transform algorithm. Usually the last 4096 ($=2^{12}$) points are selected so that effects of the start up transients are reduced while performing the fourier analysis.

b. The time histories are processed by a cosine taper window (see p. 325 of reference 3) to reduce effects of leakage and the processed data are stored in array A(I).

After processing the time histories, subroutine FFT is called to carry out the fourier transformation. The results are returned through array A(I) in form of complex fourier transforms. The transforms are converted to spectral densities for each of the 4096 frequencies using equation 9.134 of reference 3. This information is condensed in terms of spectral densities for a set of discrete frequencies FR(I) which are evenly spread on a logarithmis scale from wavelength XDEL (profile elevation interval) to 4096 XDEL. For this condensing operation the spectral densities around each of these discrete frequencies are averaged. All the spectral densities are also divided by a factor 0.875 to compensate for the effects of the cosine taper window (reference 3, p. 327).

Finally, an approximate value of RMS for the variable time history is calculated by adding average areas under the spectral density curve.

A.3.2.2 Input

The input to the program is in form of a tape and a data card

a. Tape - This tape stores time histories of the variables generated by the vehicle simulation program. It can be created by inserting statements, such as the following statements, at the two places marked by commend cards in subroutine DYSYS of the program.

Place 1

```
      C STATISTICAL PROCESSING OPTION , SEE DESCRIPTION OF PROGRAM SPEC IN
      C THE USER MANUAL FOR THE CARDS TO BE INSERTED HERE FOR
      C EXCERCISING THE OPTION
      C NCUR IS THE TOTAL NUMBER OF VARIABLES SELECTED
85          NCUR=10
            FV42=FV4/2.
            FH42=FH4/2.
```

```
      WRITE (9,173) NCUR, SPEED, ITIRE, YRMS
      WRITE (9,174) YW2,YW3,YW4,FV2,FV42,FH2,FH42,D2YW2,
           D2YW4,D2Y0
173   FORMAT (1X,I2,E10.4,I2,F10.4)
174   FORMAT (1X,10E12.4)
```

Where tape 9 is used as a storage tape and it is specified as so in the program.

Place 2

```
      C STATISTICAL PROCESSING OPTION , SEE DESCRIPTION OF PROGRAM SPEC IN
140   C THE USER MANUAL FOR THE CARDS TO BE INSERTED HERE FOR
      C EXCERCISING THE OPTION
            FV42=FV4/2.
            FH42=FH4/2.
```

```
      WRITE (9,174) YW2, YW3, YW4, FV2, FV42, FH2, FH42, D2YW2,
           D2YW4, D2Y0
```

b. Data Card - The total number of points in each of the time histories is needed in I6 format (this number is available as TOTAL STEPS in the vehicle simulation program output).

A.3.2.3 Output

The program output consists of (a) the spectral density values for a set of reduced frequencies, (b) the corresponding values of spectral densities for the frequencies in Hertz, (c) log values of all the spectral densities.

The printout is repeated for each of the NCUR variables. On the top of each set tire model no., speed, RMS value of the terrain profile, and the variable serial number are printed. The approximate RMS value of each variable is printed at the bottom of the set.

A.3.2.4 Listing

The following is a listing of the program.

```
PROGRAM SPEC        74/74    OPT=1                    FTN 4.6+433B       01/10/78  11.00.54       PAGE     1

      PROGRAM SPEC(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE8)
C PROGRAM TO DETERMINE SPECTRAL DENSITIES OF THE SELECTED VARIABLES
      DIMENSION XQ(15)
      DIMENSION F(4980),FR(55)
      COMPLEX A(4096),W,X,Y,WTAB(4095)
      READ(5,2)NPTTS
    2 FORMAT(I6)
      KC=1
    7 READ(8,173)NCUR,SPEED,ITIRE,YRMS
  173 FORMAT(1X,I2,F10.4,I2,F10.4)
      DO 4 II=1,NPTTS
      READ(8,172)(XQ(I),I=1,NCUR)
  172 FORMAT(1X,10E12.4)
      F(II)=XQ(KC)
    4 CONTINUE
      DO 150 I=1,4096
      J=I+(NPTTS-4096)
      F(I)=F(J)
  150 CONTINUE
      WRITE(6,175)
  175 FORMAT(1H1)
      YRMS=YRMS*12.
      SPEEDM=SPEED*3600./5280.
      WRITE(6,176)ITIRE,YRMS,KC,SPEEDM
  176 FORMAT(10X,*TIRE MODEL NO.*,I5,5X,*YRMS*,F10.4,5X,*INCHES*/10X,
     1*VARIABLE NO.*,I5,5X,*SPEED*,F10.4,5X,*MPH*//)
      WRITE(6,177)
      WRITE(6,178)
  177 FORMAT(1X,*   REDUCED FREQ       PSD            LOG PSD
     1 FREQUENCY          PSD          LOG PSD*)
  178 FORMAT(1X,*         RAD/FT     SQ VAR.FT/RAD
     1  HERTZ        SQ VAR/HERTZ*)
      EL=1./2.
      FL=0.078125*(2.**EL)
      DO 70 J=1,55
      AG=(FLOAT(J-1))/6.
      FR(J)=FL*2.**AG
   70 CONTINUE
      NN=12
      NNI=4096
      AN=NNI
      DX=0.1
      BN=AN*DX
      AM=400.
      M1=AM+1
      M2=NNI-AM
      DOMG=2.*3.14159/BN
      DO 12 I=1,NNI
      XA=(I-1.)*3.14159/AM
      IF(I.LE.M1)A(I)=F(I)*(1.-COS(XA))*0.5
      IF(I.GT.M1)A(I)=F(I)
      XB=(AN-I)*3.14159/AM
      IF(I.GE.M2)A(I)=F(I)*(1.-COS(X3))*0.5
   12 CONTINUE
      CALL FFT(A,NN,0,WTAB,1)
      SUM=0.
      SPEKP=0.
```

```
      OMEGAP=0.
      N=1
      J=1
   14 SUMM=0.
      DO 13 I=N,NNI
      M=I
      OMEGA=2.*3.14159/BN*M
      SPEK=2.*(REAL(A(I))**2)+2.*(AIMAG(A(I))**2)
      SPEK=SPEK/DOMG
      IF(OMEGA.LT.FR(1))GO TO 45
      SUMM=SUMM+SPEK
      JK=2*(J-KJ1)+1
      OMEG1=OMEGA+DOMG
      IF(OMEG1.GE.FR(JK))GO TO 46
   13 CONTINUE
   46 JJ=I-N+1
      JL=JK-1
      SPEK=SUMM/JJ
      OMEGA=FR(JL)
      N=I+1
      GO TO 47
   45 N=N+1
      KJ1=J
   47 SPEK=SPEK/0.875
      SUM=SUM+(OMEGA-OMEGAP)*(SPEK+SPEKP)/2.
      OMEGAP=OMEGA
      SPEKP=SPEK
      SPEKL=ALOG10(SPEK)
      SPEKF=SPEK*2.*3.14159/SPEED
      SPEKFL=ALOG10(SPEKF)
      FREQ=OMEGA*SPEED/2./3.14159
      WRITE(6,33)OMEGA,SPEK,SPEKL,FREQ,SPEKF,SPEKFL
   33 FORMAT(4X,F12.6,2E16.8,5X,F12.6,2E16.8)
      J=J+1
      IF(OMEGA.GE.FR(53))GO TO 134
      GO TO 14
  134 RMS=SQRT(SUM)
      WRITE(6,34)RMS
   34 FORMAT(1X,*RMS = *,E16.8)
      IF(KC.EQ.NCUR)GO TO 6
      KC=KC+1
      REWIND 8
      GO TO 7
    6 CONTINUE
      END
```

```
      SUBROUTINE FFT(A,NBITS,INV,WTAB,NEWTB)
C FAST FOURIER TRANSFORM
C A=COMPLEX ARRAY OF 2**NBITS DATA POINTS TO BE TRANSFORMED
C  NBITS=LOG2(N) WHERE N=NO. OF DATA POINTS
C INV SPECIFIES THE TRANSFORM DIRECTION
C  INV=0 FOR TIME TO FREQUENCY
C  NON ZERO FOR FREQUENCY TO TIME
C WTAB=SIN TABLE STORAGE
C NEWTAB SPECIFIES IF A NEW SIN TABLE IS TO BE CALCULATED
C (=0 NO NEW TABLE OTHERWISE CALCULATES NEW TABLE)
      COMPLEX A(4096),W,X,Y,WTAB(4095)
      N=2**NBITS
      FN=N
      IF(INV.NE.0)GO TO 20
      DO 10 I=1,N
   10 A(I)=CONJG(A(I))/FN
   20 IF(NEWTB.EQ.0)GO TO 40
      TPIN=6.2831/FN
      N2=N/2
      DO 30 NB=1,N2
   30 WTAB(NB)=CEXP(CMPLX(0.0,TPIN*FLOAT(IRVB(NB-1,NBITS-1))))
   40 NBLOCK=1
      NSEP=N
      DO 60 NS=1,NBITS
      NSEP=NSEP/2
      DO 50 NB=1,NBLOCK
      W=WTAB(NB)
      DO 50 J=1,NSEP
      N1=J+(NB-1)*NSEP*2
      N2=N1+NSEP
      X=W*A(N2)
      Y=A(N1)+X
      A(N2)=A(N1)-X
   50 A(N1)=Y
   60 NBLOCK=NBLOCK*2
      DO 80 I=1,N
      J=IRVB(I-1,NBITS)+1
      IF(I.GE.J)GO TO 70
      X=A(I)
      A(I)=A(J)
      A(J)=X
   70 IF(INV.EQ.0)A(I)=CONJG(A(I))
   80 CONTINUE
      RETURN
      END
```

```
      FUNCTION IRVB(N,NBITS)
      M=N
      IRVB=0
      DO 10 I=1,NBITS
      MN=M/2
      IRVB=IRVB*2
      IF(M.NE.MN*2)IRVB=IRVB+1
   10 M=MN
      RETURN
      END
```

TIRE MODEL NO. 3 YRMS .9996 INCHES
VARIABLE NO. 1 SPEED 18.0000 MPH

REDUCED FREQ RAD/FT	PSD SQ VAR.FT/RAD	LOG PSD	FREQUENCY HERTZ	PSD SQ VAR/HERTZ	LOG PSD
.015340	7.51601416E-03	-2.12401253E+00	.064453	1.78880520E-03	-2.74743695E+00
.030680	1.19238121E-03	-2.92358488E+00	.128906	2.83765825E-04	-3.54700930E+00
.046019	3.88328802E-04	-3.41080040E+00	.193359	9.24219607E-05	-4.03422482E+00
.061359	1.68134961E-03	-2.77434197E+00	.257812	4.00159933E-04	-3.39776640E+00
.076699	2.58647847E-03	-2.58729113E+00	.322266	6.15579916E-04	-3.21071556E+00
.092039	1.85536734E-03	-2.73157009E+00	.386719	4.41576022E-04	-3.35499452E+00
.107379	8.58882721E-03	-2.06606613E+00	.451172	2.04413437E-03	-2.68949056E+00
.124016	6.09491679E-02	-1.21503222E+00	.521076	1.45058558E-02	-1.83845664E+00
.156250	1.04222678E-01	-9.82037771E-01	.656515	2.48049184E-02	-1.60545220E+00
.196863	7.94787360E-03	-2.09974905E+00	.827157	1.89158790E-03	-2.72317347E+00
.248031	1.50846032E-02	-1.82146611E+00	1.042152	3.59012413E-03	-2.44489034E+00
.312500	1.82882176E-02	-1.73782862E+00	1.313029	4.35258194E-03	-2.36125964E+00
.393725	2.47716465E-02	-1.60604513E+00	1.654313	5.89563310E-03	-2.22946955E+00
.496063	2.12871414E-02	-1.67188265E+00	2.084304	5.06632354E-03	-2.29530708E+00
.625000	1.76953051E-03	-2.75214195E+00	2.626059	4.21146921E-04	-3.37556637E+00
.787451	1.30000580E-04	-3.88605471E+00	3.308627	3.09400396E-05	-4.50947913E+00
.992126	2.76903729E-04	-3.55454568E+00	4.168608	6.63788751E-05	-4.17797011E+00
1.250000	2.73487873E-04	-3.56306193E+00	5.252118	6.50899066E-05	-4.18648335E+00
1.574901	3.67735194E-04	-3.43446480E+00	6.617253	8.75206977E-05	-4.05788923E+00
1.984251	9.10029001E-05	-4.04094477E+00	8.337217	2.16586213E-05	-4.66435919E+00
2.500000	1.06981715E-05	-4.97069045E+00	10.504235	2.54615671E-06	-5.59411487E+00
3.149803	1.05029985E-06	-5.97872391E+00	13.234507	2.49949148E-07	-6.60214834E+00
3.968503	1.02479069E-07	-6.98936483E+00	16.674434	2.43899409E-08	-7.61278925E+00
5.000000	6.04683634E-09	-8.21847179E+00	21.008470	1.43914247E-09	-8.84189621E+00
6.299605	7.05826418E-10	-9.15130209E+00	26.449014	1.67986153E-10	-9.77472438E+00
7.937005	2.50931137E-10	-9.60044545E+00	33.348868	5.97214204E-11	-1.02238699E+01
10.000000	3.97442903E-11	-1.04007253E+01	42.016940	9.45911099E-12	-1.10241497E+01
12.599210	4.77539234E-12	-1.13209909E+01	52.938028	1.13653976E-12	-1.19444154E+01
15.874011	2.12262799E-12	-1.16731261E+01	66.697735	5.05183854E-13	-1.22965505E+01
20.000000	3.51955685E-13	-1.24535120E+01	84.033881	8.37651864E-14	-1.30769364E+01
25.198421	2.53391786E-13	-1.25962085E+01	105.876055	6.03069102E-14	-1.32196329E+01
31.748021	9.48012910E-13	-1.20231657E+01	133.395471	2.25626354E-13	-1.26466102E+01
40.000000	3.04172981E-13	-1.25168794E+01	168.067762	7.23929390E-14	-1.31403038E+01
50.396842	8.97292702E-11	-1.00470659E+01	211.752111	2.13554983E-11	-1.05704903E+01

RMS = 1.16493213E-01

A.4 Listing of the Simulation Program


```
      PROGRAM TIRE(INPUT,OUTPUT,PUNCH,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7=
     1PUNCH,TAPE8)
C********TERRAIN TIRE VEHICLE SIMULATION PROGRAM *************
C*************************************************************************
C DEVELOPED BY A. BOGHANI AND R. FISH
C FOSTER-MILLER ASSOCIATES, WALTHAM,MASS. 02154
C (617) 890-3200
C
C
C THIS PROGRAM SIMULATES OPERATION OF A THREE AXLE TRUCK OVER A
C GIVEN PROFILE
C IT CAN BE USED TO CREATE AXLE DISPLACEMENT RECORDS FOR USE
C ON THE VEHICLE SHAKE TEST STAND
C
      REAL MH,IH,MB,IB,M2,M3,M4,K2,K3,JN2,JN3,L2,L3,KSTOP,KT
      COMMON/IONUM/NWT,NRD,LABEL(80)
      COMMON/STATE/THETA,DTHETA,PHI,DPHI,Y0,DY0,YW2,DYW2,YW3,DYW3,YW4,
     1DYW4
      COMMON/SECV/Y2,DY2,Y3,DY3,Y4,DY4,YB,DYB,D2YB,D2Y0,D2PHI,D2THETA,
     1D2YW2,D2YW3,D2YW4,DEL2,DEL3,DEL4,YSP2,YSP3,YSP4,YST2,YST3,YST4
      COMMON/FORCE/FV2,FV3,FV4,FH2,FH3,FH4,FY2,FSY3,FSY4,FX2,FSX3,FSX4,
     1FFS,FBS,FX34,FY34,WTR2,WTR3,WTR4
      COMMON/VEHCL/MH,IH,MB,IB,M2,M3,M4,L2,L3,S34,SFS,SBS,SB,A,HS,KSTOP,
     1SPEED,GG,HSTOP,STGAP
      COMMON/SPSN/K2,JN2,RB2,K3,JN3,RB3,SN,B2VJ,B2VR
      COMMON/DYNAMIC/TIME,DTIME,FTIME,DER(12),JREAR,MM
      COMMON/XYPLT/NPLTM,NPLT(10),PLT(10,500),XREAR,JPL,IXAX
     1,PLSTR,PLSTP,LIMP
      COMMON/GRND/TER(500),OTER(500),DYX(500),ODYX(500),JMAX,MW,NW,XDEL
     1,YRMS
      COMMON/TIRE/KT,BT,RAD,CONL,BS,AKC,ABC,PRESS,TLIM,TSTIF,ITIRE
      COMMON/PHASE/IPHS,LPHS,KPHS,NXT,IXT,JSTP,JPHS
      COMMON/ADMDL/ADDT,ADSDT,ADTH(40),ADDX(40),ADST(40),ADCT(40),
     1ADTT(40),NSG(40),NADS,NBACK,NAD2,ISCHEM,Y1,JGR,FXX,FYY,TLENT
     2,YI12,YI13,YI14,DYW,TERI2,TERI3,TERI4
      NWT=6
      NRD=5
C
C...DATA ACQUISITION
      CALL PROGIO
      SPEED=SPEED*5280./3600.
      YRMS=YRMS/12.
      PRESS=PRESS*144.
      AKC=AKC*12.**3
C IPHS IS DIMENSION OF TER ETC.
C LIMP IS Y DIMENSION OF PLT
      IPHS=500
      LIMP=500
      DO 10 J=1,IPHS
      TER(J)=0.0
   10 CONTINUE
      ISCHEM=1
      LPHS=1
      CALL PROFILE
C
C...INITIAL CONDITIONS
      YW2=TER(1+MW)
```

```
          YW3=TER(1+NW)
          YW4=TER(1)
          YB:(YW3+YW4)/2.
          PHI=ASIN((YW4-YW3)/2./A)
          THETA=ASIN((YB-YW2)/(L3+L2))
          YO:YB-L3*SIN(THETA)
          DYO=0.
          DYW2=0.
          DYW3=0.
          DYW4:0.
          DPHI=0.
          DTHETA=0.
          TERI2=TER(1+MW)
          TERI3:TER(1+NW)
          TERI4=TER(1)
C
C...DYNAMIC SIMULATION
          CALL DYSYS
C
          END
```

```
      SUBROUTINE PROGIO
C DATA ACQUISITION SUBROUTINE
      REAL MH,IH,MB,IB,M2,M3,M4,K2,K3,JN2,JN3,L2,L3,KSTOP,KT
      COMMON/IONUM/NWT,NRD,LABEL(80)
      COMMON/VEHCL/MH,IH,MB,IB,M2,M3,M4,L2,L3,S34,SFS,SBS,SB,A,HS,KSTOP,
     1SPEED,GG,HSTOP,STGAP
      COMMON/SPSN/K2,JN2,RB2,K3,JN3,RB3,SN,B2VJ,B2VR
      COMMON/DYNAMIC/TIME,DTIME,FTIME,DER(12),JREAR,MM
      COMMON/TIRE/KT,BT,RAD,CONL,BS,AKC,ABC,PRESS,TLIM,TSTIF,ITIRE
      COMMON/XYPLT/NPLTM,NPLT(10),PLT(10,500),XREAR,JPL,IXAX
     1,PLSTR,PLSTP,LIMP
      COMMON/GRND/TER(500),OTER(500),DYX(500),ODYX(500),JMAX,MW,NW,XDEL
     1,YRMS
      DIMENSION JPLT(50)
      WRITE(NWT,9005)
 9005 FORMAT(1H1)
      CALL IOLAB2(3)
      CALL IOLAB(3)
      WRITE(NWT,9004)
 9004 FORMAT(2X,//)
      CALL IOLAB(3)
      READ(NRD,9070)(LABEL(I),I=1,40),ITIRE
      IF(ITIRE.EQ.1)WRITE(NWT,9081)
      IF(ITIRE.EQ.2)WRITE(NWT,9082)
      IF(ITIRE.EQ.3)WRITE(NWT,9083)
      IF(ITIRE.EQ.4)WRITE(NWT,9084)
 9081 FORMAT(20X,70H                           TIRE MODEL          - POINT CONT
     1ACT                ,/)
 9082 FORMAT(20X,70H                           TIRE MODEL          - RIGID TREA
     1D BAND             ,/)
 9083 FORMAT(20X,70H                           TIRE MODEL          - FIXED FOOT
     1PRINT              ,/)
 9084 FORMAT(20X,70H                           TIRE MODEL          - ADAPTIVE F
     1OOTPRINT           ,/)
      CALL IOLABD(SPEED)
      CALL IOLABD(YRMS)
      WRITE(NWT,9002)
 9002 FORMAT(1X,/)
      CALL IOLAB(1)
      CALL IOLABD(MH)
      CALL IOLABD(MB)
      CALL IOLABD(M2)
      CALL IOLABD(M3)
      CALL IOLABD(M4)
      CALL IOLABD(IH)
      CALL IOLABD(IB)
      CALL IOLABD(L2)
      CALL IOLABD(L3)
      CALL IOLABD(GG)
      CALL IOLABD(S34)
      CALL IOLABD(SFS)
      CALL IOLABD(SBS)
      CALL IOLABD(SB)
      CALL IOLABD(A)
      CALL IOLABD(HS)
      CALL IOLABD(KSTOP)
      CALL IOLABD(HSTOP)
```

```
      CALL IOLABD(STGAP)
      WRITE(NWT,9002)
      CALL IOLAB(2)
      CALL IOLABD(K2)
      CALL IOLABD(B2VJ)
      CALL IOLAB7(B2VR)
      CALL IOLABD(JN2)
      CALL IOLAB7(RB2)
      CALL IOLAB(1)
      CALL IOLABD(K3)
      CALL IOLABD(JN3)
      CALL IOLABD(RB3)
      CALL IOLABD(SN)
      WRITE(NWT,9002)
      CALL IOLAB(1)
      CALL IOLABD(KT)
      CALL IOLABD(BT)
      CALL IOLABD(RAD)
      CALL IOLABD(CONL)
      CALL IOLABD(BS)
      CALL IOLABD(AKC)
      CALL IOLABD(ABC)
      CALL IOLABD(PRESS)
      CALL IOLABD(TLIM)
      CALL IOLABD(TSTIF)
      READ(NRD,9070)(LA3EL(I),I=1,40),MM
 9070 FORMAT(40A1,I5)
      READ(NRD,9071)(JPLT(K),K:1,40),IXAX,PLSTR,PLSTP
 9071 FORMAT(41I1,9X,2F10.3)
      L=1
      DO 61 K=1,40
      IF(JPLT(K))62,61,52
   62 NPLT(L)=K
      L=L+1
   61 CONTINUE
      NPLTM:L-1
      RETURN
      END
```

```
      SUBROUTINE PROFILE
C PROFILE DATA ACQUISITION AND PROCESSING SUBROUTINE
C THE ACQUISITION IS CARRIED OUT IN PHASES TO ACCOMODATE
C LENGTHY PROFILE IN LIMITED MEMORY
      REAL MH,IH,MB,IB,M2,M3,M4,K2,K3,JN2,JN3,L2,L3,KSTOP,KT
      COMMON/VEHCL/MH,IH,MB,IB,M2,M3,M4,L2,L3,S34,SFS,SBS,SB,A,HS,KSTOP,
     1SPEED,GG,HSTOP,STGAP
      COMMON/DYNAMIC/TIME,DTIME,FTIME,DER(12),JREAR,MM
      COMMON/TIRE/KT,BT,RAD,CONL,BS,AKC,ABC,PRESS,TLIM,TSTIF,ITIRE
      COMMON/IONUM/NWT,NRD,LABEL(8C)
      COMMON/GRND/TER(500),OTER(500),DYX(500),ODYX(500),JMAX,MW,NW,XDEL
     1,YRMS
      COMMON/PHASE/IPHS,LPHS,KPHS,NXT,IXT,JSTP,JPHS
      COMMON/XYPLT/NPLTM,NPLT(10),PLT(10,500),XREAR,JPL,IXAX
     1,PLSTR,PLSTP,LIMP
      IF(LPHS.GT.1)GO TO 40
C
C***************************************************************************
C         PART 1, EXECUTED ONLY INTIALLY
      READ(NRD,1)XDEL,JMAX
    1 FORMAT(F10.2,I5)
    2 FORMAT(8E10.3)
C
C DETERMINE THE NUMBER OF DATA POINTS UNDER THE TRUCK
      MEO=IFIX((L2+L3+A)/XDEL)
      MW=MEO
      XTEST=(L3+L2+A)/XDEL-FLOAT(MEO)
      IF(XTEST.GE.0.5)MW=MEO+1
      JFIN=JMAX-MW-1
      IF(JFIN.LE.0)WRITE(NWT,13)
   13 FORMAT(10X,*TERRAIN LENGTH INSUFFICIENT*)
      NEO=IFIX(2.*A/XDEL)
      NW=NEO
      XTEST=(2.*A/XDEL)-FLOAT(NEO)
      IF(XTEST.GE.0.5)NW=NEO+1
C
C FIX THE TIME SCALE
      DTIME=XDEL/SPEED
      FTIME=DTIME*FLOAT(JFIN-1)
      FTIME=FTIME*0.99
      TIME=0.
C
      IF(ITIRE.EQ.4)CALL APRINT
C
C SETTING MARGINES FOR PHASE SIMULATION
      JR=IFIX(RAD/XDEL)+1
      JL=IFIX(CONL/XDEL/2.)+1
      IF(ITIRE.EQ.1)JSTP=0
      IF(ITIRE.EQ.2)JSTP=JR
      IF(ITIRE.EQ.3)JSTP=JL
      IF(ITIRE.EQ.4)JSTP=JR
C
C MAKE SURE THAT NUMBER OF DATA READ IS DIVISIBLE BY 8
      ITEST=IPHS
   95 XTEST=8.*FLOAT(ITEST/8)-FLOAT(ITEST)
      IF(ABS(XTEST).LE.0.001)GO TO 94
      ITEST=ITEST-1
```

```
      GO TO 95
   94 IPHS=ITEST
C
      JREG=IFIX((PLSTP-PLSTR)/XDEL)
      NXT=JREG/LIMP+1
      IF(JMAX.LE.IPHS)IPHS=JMAX
      IF(JMAX.LE.IPHS)JSTP=0
C
C READ IN PROFILE AND CONVERT IT TO CORRECT RMS VALUE
      READ(NRD,2)(TER(J),J=1,IPHS)
      DO 50 J=1,IPHS
   50 TER(J)=TER(J)*YRMS
C
      JPHS=IPHS-MW-JSTP
      GO TO 43
C
C**************************************************************************
C         PART2, EXECUTED ONLY SUBSEQUENTLY
C
C MAKE SURE THAT NUMBER OF DATA READ IS DIVISIBLE BY 8
   40 ITEST=IPHS-MW-1-2*JSTP
   45 XTEST=8.*FLOAT(ITEST/8)-FLOAT(ITEST)
      IF(ABS(XTEST).LE.0.001)GO TO 44
      ITEST=ITEST-1
      GO TO 45
   44 IPHS=ITEST+MW+1+2*JSTP
C
      IF(IPHS.GE.JMAX-JREAR+2+JSTP)IPHS=JMAX-JREAR+2+JSTP
      MW1=MW+1+2*JSTP
      MW2=MW+2+2*JSTP
C
C CONVERT LAST PART OF LAST PHASE, TO FIRST PART OF NEXT PHASE
      DO 41 I=1,MW1
   41 TER(I)=OTER(I+JPHS-1-JSTP)
C
C READ IN PROFILE AND CONVERT IT TO CORRECT RMS VALUE
      READ(NRD,2)(TER(J),J=MW2,IPHS)
      DO 51 J=MW2,IPHS
   51 TER(J)=TER(J)*YRMS
C
      JPHS=IPHS-MW-JSTP
      IF(IPHS.GE.JMAX-JREAR+2+JSTP)JPHS=IPHS-MW
C
C**************************************************************************
C         PART3, EXECUTED EACH TIME
   43 DO 20 J=1,IPHS
   20 OTER(J)=TER(J)
C
C CALCULATE TERRAIN SLOPES
      IPHS1=IPHS-1
      DO 12 I=1,IPHS1
   12 DYX(I)=(TER(I+1)-TER(I))/XDEL
      DYX(IPHS)=DYX(IPHS1)
      DO 30 J=1,IPHS
C
   30 ODYX(J)=DYX(J)
C
```

```
C CALL PROFILE FILTER SJBROUTINES, IF REQUIRED
      GO TO (22,23,24,22),ITIRE
   23 CALL RTREAD
      GO TO 22
   24 CALL FPRINT
   22 CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE RTREAD
C PROFILE FILTER SUBROUTINE FOR RIGID TREAD BAND MODEL
      REAL MH,IH,MB,IB,M2,M3,M4,K2,K3,JN2,JN3,L2,L3,KSTOP,KT
      COMMON/TIRE/KT,BT,RAD,CONL,BS,AKC,ABC,PRESS,TLIM,TSTIF,ITIRE
      COMMON/GRND/TER(500),OTER(500),DYX(500),ODYX(500),JMAX,MW,NW,XDEL
     1,YRMS
      COMMON/PHASE/IPHS,LPHS,KPHS,NXT,IXT,JSTP,JPHS
      DIMENSION ST(50),G(50),IS(50),XC(50),JPC(50),TPT(50),YTER(50)
      DIMENSION XT(50),SW(50),JPT(50)
      DIMENSION DYC(50)
      NS=IFIX(RAD/XDEL)+1
      IF(NS.LT.4)NS=4
      XSEG=RAD/FLOAT(NS)
      XSEG=0.9993*XSEG
      NS2=1+2*NS
      JR=IFIX(RAD/XDEL)+1
      DO 11 I=1,NS2
      XT(I)=FLOAT(I-NS-1)*XSEG
C
C CALCULATE TIRE PERIPHERY SLOPES
      SW(I)=XT(I)/(SQRT(RAD*RAD-XT(I)*XT(I)))
C
      IF(XT(I).LT.0.0)GO TO 15
      JPT(I)=IFIX(XT(I)/XDEL)
      GO TO 11
   15 JPT(I)=-IFIX(ABS(XT(I))/XDEL)-1
   11 CONTINUE
      JR1=JR+1
      JRJ=IPHS-JR
      DO 121 J=JR1,JRJ
      K=0
      DO 20 I=1,NS2
      JJPT=J+JPT(I)
      JJPT1=J+JPT(I)+1
C
C CALCULATE TERRAIN SLOPES
      ST(I)=DYX(JJPT)+(DYX(JJPT1)-DYX(JJPT))*(XT(I)-FLOAT(JPT(I))*XDEL)
     1/XDEL
C
      G(I)=ST(I)-SW(I)
C...IS=0 FOR NEGATIVE G(I), =1 FOR POSITIVE SIGN
      IS(I)=1
      XTEST=G(I)+ABS(G(I))
      IF(XTEST.LE.0.00001)IS(I)=0
      IF(I.EQ.1)GO TO 20
      IDEC=0
      IF(IS(I).EQ.0.AND.IS(I-1).EQ.1)IDEC=1
      IF(IDEC.EQ.0)GO TO 20
      SLOPE=(G(I)-G(I-1))/(XT(I)-XT(I-1))
      K=K+1
C...XC ARE POSSIBLE CONTACT POINT DISTANCES
      XC(K)=XT(I)-G(I)/SLOPE
      DYC(K)=ST(I)-G(I)*(ST(I)-ST(I-1))/(G(I)-G(I-1))
   20 CONTINUE
      DO 30 I=1,K
      IF(XC(I).LE.0.0)GO TO 16
      JPC(I)=IFIX(XC(I)/XDEL)
```

```
      GO TO 17
   15 JPC(I)=-IFIX(ABS(XC(I)/XDEL))-1
   17 JJPC=J+JPC(I)
      TPT(I)=OTER(JJPC)+DYX(JJPC)*(XC(I)-XDEL*FLOAT(JPC(I)))
      YTER(I)=TPT(I)+SQRT(RAD*RAD-XC(I)*XC(I))
   30 CONTINUE
C
C DETERMINE THE MAXIMUM OF THE ELEVATIONS FOR THE POSSIBLE
C CONTACT POINTS
      TER(J)=YTER(1)
      DO 40 I=1,K
      IF(YTER(I).LE.TER(J))GO TO 40
      TER(J)=YTER(I)
      DYX(J)=DYC(I)
   40 CONTINUE
C
  121 CONTINUE
      DO 122 J=1,JR
      DYX(J)=0.0
  122 TER(J)=TER(JR1)
      JRJ1=JRJ+1
      DO 123 J=JRJ1,IPHS
      DYX(J)=0.0
  123 TER(J)=TER(JRJ)
C...REMOVE RADIUS BIAS FROM TERRAIN PROFILE
      DO 124 J=1,IPHS
  124 TER(J)=TER(J)-RAD
      RETURN
      END
```

```
      SUBROUTINE FPRINT
C PROFILE FILTER SUBROUTINE FOR FIXED FOOTPRINT MODEL
      REAL MH,IH,MB,IB,M2,M3,M4,K2,K3,JN2,JN3,L2,L3,KSTOP,KT
      COMMON/TIRE/KT,BT,RAD,CONL,BS,AKC,ABC,PRESS,TLIM,TSTIF,ITIRE
      COMMON/GRND/TER(500),OTER(500),DYX(500),ODYX(500),JMAX,MW,NW,XDEL
     1,YRMS
      COMMON/PHASE/IPHS,LPHS,KPHS,NXT,IXT,JSTP,JPHS
      JL=IFIX(CONL/XDEL/2.)+1
      MFF=2*JL-1
      JR1=JL+1
      JRJ=IPHS-JL
C DETERMINE AVERAGE TERRAIN ELEVATION AND SLOPE UNDER TIRE FOOTPRINT
      DO 121 J=JR1,JRJ
      SDYX=0.
      STER=0.0
      DO 10 I=1,MFF
      STER=STER+OTER(J-JL+I)
      SDYX=SDYX+ODYX(J-JL+I)
   10 CONTINUE
      TER(J)=STER/MFF
      DYX(J)=SDYX/MFF
  121 CONTINUE
      DO 122 J=1,JL
      DYX(J)=0.0
  122 TER(J)=TER(JR1)
      JRJ1=JRJ+1
      DO 123 J=JRJ1,IPHS
      DYX(J)=0.0
  123 TER(J)=TER(JRJ)
      RETURN
      END
```

```
      SUBROUTINE APRINT
C SUBROUTINE TO DIVIDE TIRE INTO SECTORS FOR ADAPTIVE FOOTPRINT
C MODEL AND DETERMINE VALUES OF ASSOCIATED PARAMETERS
      COMMON/ADMDL/ADDT,ADSDT,ADTH(40),ADDX(40),ADST(40),ADCT(40),
     1ADTT(40),NSG(40),NADS,NBACK,NAD2,ISCHEM,Y1,JGR,FXX,FYY,TLENT
     2,YI12,YI13,YI14,DYW,TERI2,TERI3,TERI4
      COMMON/TIRE/KT,BT,RAD,CONL,BS,AKC,ABC,PRESS,TLIM,TSTIF,ITIRE
      COMMON/GRND/TER(500),OTER(500),DYX(500),ODYX(500),JMAX,MW,NW,XDEL
     1,YRMS
      NADS=9
      NAD1=NADS+1
      NBACK=NADS+2
      NAD2=2*NADS+1
      ADDT=0.523/FLOAT(NADS)
      ADSDT=SIN(ADDT/2.)
C SECTORS ON RIGHT(FORWARD) SIDE OF THE VERTICAL
      DO 10 I=1,NAD1
      ADTH(I)=FLOAT(I-1)*ADDT
      ADST(I)=SIN(ADTH(I))
      ADCT(I)=COS(ADTH(I))
      ADTT(I)=TAN(ADTH(I))
      YY=RAD*ADST(I)
      NSG(I)=IFIX(YY/XDEL)
      ADDX(I)=YY-XDEL*FLOAT(NSG(I))
   10 CONTINUE
C SECTORS ON LEFT(REAR) SIDE OF THE VERTICAL
      DO 20 I=NBACK,NAD2
      ADTH(I)=-FLOAT(I-NAD1)*ADDT
      ADST(I)=SIN(ADTH(I))
      ADCT(I)=COS(ADTH(I))
      ADTT(I)=TAN(ADTH(I))
      YY=-RAD*ADST(I)
      NSG(I)=-IFIX(YY/XDEL)
      ADDX(I)=-YY-XDEL*FLOAT(NSG(I))
   20 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE DYSYS
C DYNAMIC SIMULATION SUBROUTINE
C THIS SUBROUTINE COORDINATES THE DYNAMIC SIMULATION AND GENERATES
C OUTPUTS ON PRINTER,PLOTTER AND PUNCH
      REAL MH,IH,MB,IB,M2,M3,M4,K2,K3,JN2,JN3,L2,L3,KSTOP,KT
      COMMON/IONUM/NWT,NRD,LABEL(80)
      COMMON/STATE/THETA,DTHETA,PHI,DPHI,Y0,DY0,YW2,DYW2,YW3,DYW3,YW4,
     1DYW4
      COMMON/SECV/Y2,DY2,Y3,DY3,Y4,DY4,YB,DYB,D2YB,D2Y0,D2PHI,D2THETA,
     1D2YW2,D2YW3,D2YW4,DEL2,DEL3,DEL4,YSP2,YSP3,YSP4,YST2,YST3,YST4
      COMMON/FORCE/FV2,FV3,FV4,FH2,FH3,FH4,FY2,FSY3,FSY4,FX2,FSX3,FSX4,
     1FFS,FBS,FX34,FY34,WTR2,WTR3,WTR4
      COMMON/VEHCL/MH,IH,MB,IB,M2,M3,M4,L2,L3,S34,SFS,SBS,SB,A,HS,KSTOP,
     1SPEED,GG,HSTOP,SIGAP
      COMMON/SPSN/K2,JN2,RB2,K3,JN3,RB3,SN,B2VJ,B2VR
      COMMON/TIRE/KT,BT,RAD,CONL,BS,AKC,ABC,PRESS,TLIM,TSTIF,ITIRE
      COMMON/DYNAMIC/TIME,DTIME,FTIME,DER(12),JREAR,MM
      COMMON/XYPLT/NPLTM,NPLT(10),PLT(10,500),XREAR,JPL,IXAX
     1,PLSTR,PLSTP,LIMP
      COMMON/GRND/TER(500),OTER(500),DYX(500),ODYX(500),JMAX,MW,NW,XDEL
     1,YRMS
      COMMON/PHASE/IPHS,LPHS,KPHS,NXT,IXT,JSTP,JPHS
      COMMON/ADMDL/ADDT,ADSDT,ADTH(40),ADDX(40),ADST(40),ADCT(40),
     1ADTT(40),NSG(40),NADS,NBACK,NAD2,ISCHEM,Y1,JGR,FXX,FYY,TLENT
     2,YI12,YI13,YI14,DYW,TERI2,TERI3,TERI4
      DIMENSION IBUF(1000)
C
C DETERMINE THE EQULIBRIUM DEFLECTION OF THE SUSPENSION AND TIRES
      WTR2=(MH*32.2/2.*L3/(L2+L3)+M2*32.2)
      WTR3=(MH*32.2/4.*L2/(L2+L3)+M3*32.2+MB*32.2/4.)/2.
      WTR4=(MH*32.2/4.*L2/(L2+L3)+M4*32.2+MB*32.2/4.)/2.
      YSP2=(MH*32.2/2.*L3/(L2+L3))/K2
      YSP3=(MH*32.2/4.*L2/(L2+L3)+MB*32.2/4.)/K3
      YSP4=(MH*32.2/4.*L2/(L2+L3)+MB*32.2/4.)/K3
      IF(ITIRE.EQ.4)GO TO 81
      YST2=WTR2/KT
      YST3=WTR3/KT
      YST4=WTR4/KT
      GO TO 80
   81 DO 83 JADPT=1,3
      IF(JADPT.EQ.1)JGR=1+MW
      IF(JADPT.EQ.1)WEIGHT=WTR2
      IF(JADPT.EQ.2)JGR=1+NW
      IF(JADPT.EQ.2)WEIGHT=WTR3
      IF(JADPT.EQ.3)JGR=1
      IF(JADPT.EQ.3)WEIGHT=WTR4
      CEY=2.
   84 ARO=CEY*RAD
      Y1=ARO+TER(JGR)
      CALL ADAPT
      GX=FYY/WEIGHT-1.
      IF(GX)85,85,86
   85 CEY=CEY-0.025
      GO TO 84
   86 CEY=CEY+0.025
   83 ARO=CEY*RAD
      Y1=ARO+TER(JGR)
```

```
      CALL ADAPT
      GX=FYY/WEIGHT-1.
      IF(GX)87,87,88
   87 CEY=CEY-0.0025
      GO TO 89
   89 GO TO (91,92,93),JADPT
   91 YI12=Y1
      GO TO 83
   92 YI13=Y1
      GO TO 83
   93 YI14=Y1
   83 CONTINUE
   80 CONTINUE
      REWIND 8
C
C
      CALL SECOND(TT1)
      JREAR=1
      KPHS=1
      JXT=1
      IXT=0
      CALL STEQU
C
C STATISTICAL PROCESSING OPTION , SEE DESCRIPTION OF PROGRAM SPEC IN
C THE USER MANUAL FOR THE CARDS TO BE INSERTED HERE FOR
C EXCERCISING THE OPTION
C NCUR IS THE TOTAL NUMBER OF VARIABLES SELECTED
      NCUR=10
      FV42=FV4/2.
      FH42=FH4/2.
C
      XREAR=FLOAT(JREAR-1)*XDEL
C
C STORE SELECTED VARIABLES FOR PLOTTING
      IF(NPLTM)65,64,65
65    IF(PLSTR.LE.XDEL) IXT=1
      IF(PLSTR.LE.XDEL) CALL PSTORE
   64 CONTINUE
C
      J=1
      I=MM
      K=10
   15 IF(FTIME-TIME)10,11,11
   11 IK=K-10
      IF(IK)13,14,13
C
C WRITE HEADING AT EVERY 10 PRINTED STEPS
   14 WRITE(NWT,9004)
      WRITE(NWT,9006)
      WRITE(NWT,9001)
      WRITE(NWT,9002)
      WRITE(NWT,9003)
 9004 FORMAT(1H1)
 9006 FORMAT(43X,*DYNAMIC SIMULATION*/)
 9001 FORMAT(1X,* NO.  TIME    FV2      FV3      FV4      FH2      F
     1H3      FH4      YW2      YW3      YW4      Y3     THETA,DEG
     2PHI,DEG  *)
```

```
      9002 FORMAT(1X,*             DEL2      DEL3      DEL4      Y2        Y3
     1        Y4        Y8        FY2       FSY3      FSY4 *)
      9003 FORMAT(1X,*             FFS       FBS       D2Y0      D2Y8      D2Y
     1W2      D2YW3     D2YW4     D2THETA   D2PHI    *//)
C
           K=0
        13 IL=I-MM
           WRITE(8)TIME,YW2,YW3,YW4
           IF(IL)16,17,16
        17 THETAC=THETA*180./3.14159
           PHIC=PHI*180./3.14159
           WRITE(NWT,9000)J,TIME,FV2,FV3,FV4,FH2,FH3,FH4,YW2,YW3,YW4,Y0,
          1THETAC,PHIC
      9000 FORMAT(1X,I4,1X,F5.3,12(E9.2,1X)/)
           WRITE(NWT,9010)DEL2,DEL3,DEL4,Y2,Y3,Y4,Y8,FY2,FSY3,FSY4
      9010 FORMAT(10X,10(E9.2,1X)/)
           WRITE(NWT,9010)FFS,FBS,D2Y0,D2Y8,D2YW2,D2YW3,D2YW4,D2THETA,D2PHI
           J=J+1
           K=K+1
           I=0
C
C CALL NUMERICAL INTEGRATION SUBROUTINE TO ADVANCE THE SIMULATION
        16 CALL RKDIF
C
C STATISTICAL PROCESSING OPTION , SEE DESCRIPTION OF PROGRAM SPEC IN
C THE USER MANUAL FOR THE CARDS TO BE INSERTED HERE FOR
C EXCERCISING THE OPTION
           FV42=FV4/2.
           FH42=FH4/2.
C
           JREAR=JREAR+1
           KPHS=KPHS+1
           I=I+1
           XREAR=FLOAT(JREAR-1)*XDEL
           IF(KPHS.LE.JPHS)GO TO 70
C
C READ IN ADDITIONAL PROFILE, IF THE PRESENT PROFILE SEGMENT HAS
C BEEN UTILIZED
           LPHS=LPHS+1
           CALL PROFILE
           KPHS=2+JSTP
C
        70 CONTINUE
C
C STORE SELECTED VARIABLES FOR PLOTTING
           IF(NPLTM)55,54,55
        55 IF(XREAR.LT.PLSTR)GO TO 54
           IF(XREAR.GT.PLSTP)GO TO 54
           IT=JXT-NXT
           IF(IT)72,71,72
        71 IXT=IXT+1
           CALL PSTORE
           JXT=0
        72 JXT=JXT+1
        54 CONTINUE
C
           GO TO 15
```

```
   10 CALL SECOND(TT2)
      TTT=TT2-TT1
      WRITE(NWT,171)TTT
  171 FORMAT(10X,*SIMULATION TIME*,5X,E10.3,5X,*SECONDS*)
      WRITE(NWT,176)JREAR
  176 FORMAT(10X,*TOTAL STEPS*,I6)
C PUNCHING WHEEL DISPLACEMENT DATA FOR CREATING RECORDS
      TSTOP=-1.0
      DO 200 IJK=1,10
200   WRITE(8)TSTOP,TSTOP,TSTOP,TSTOP
      END FILE 8
      REWIND 8
300   READ(8)T1,A1,B1,C1
      IF(T1.EQ.TSTOP) GO TO 400
      READ(8)T2,A2,B2,C2
      WRITE(7,9020)T1,A1,B1,C1,T2,A2,B2,C2
9020  FORMAT(F7.4,3F8.5,F7.4,3F8.5)
      GO TO 300
400   CONTINUE
      IF(NPLTM)66,67,66
C
C...PLOTTING
66    CALL INITPLT
      CALL PLOT(0.,-11.,-3)
      CALL PLOT(0.,2.,-3)
      JPL=IXT
      DO 69 IPLN=1,NPLTM
      CALL VPLOTS(IPLN)
   69 CONTINUE
      CALL FIN
   67 RETURN
      END
```

```
      SUBROUTINE RKDIF
C FOJRTH ORDER RUNGE KUTTA NUMERICAL ITEGRATION SUBROJTINE
      DIMENSION Y(12),SY(12),Y0(12),Y1(12),Y2(12)
      COMMON/STATE/Y
      COMMON/DYNAMIC/TIME,DTIME,FTIME, DY(12),JREAR,MM
      H=DTIME/2.0
      DO 10 I=1,12
      SY(I)=Y(I)
      Y0(I)=DY(I)
   10 Y(I)=H*DY(I)+Y(I)
      TIME=TIME+H
      CALL STEQU
      DO 20 I=1,12
      Y1(I)=DY(I)
   20 Y(I)=SY(I)+H*DY(I)
      CALL STEQU
      DO 30 I=1,12
      Y2(I)=DY(I)
   30 Y(I)=SY(I)+DTIME*DY(I)
      CALL STEQU
      TIME=TIME+H
      H=H/3.0
      DO 40 I=1,12
      PRT1=2.0*(Y1(I)+Y2(I))
      PRT2=Y0(I)+DY(I)
      Y(I)=SY(I)+H*PRT1+H*PRT2
   40  CONTINUE
      CALL STEQU
      RETURN
      END
```

```
      SUBROUTINE STEQU
C STATE EQUATIONS OF THE DYNAMIC SYSTEM
      REAL MH,IH,MB,IB,M2,M3,M4,K2,K3,JN2,JN3,L2,L3,KSTOP,KT
      COMMON/STATE/THETA,DTHETA,PHI,DPHI,Y0,DY0,YW2,DYW2,YW3,DYW3,YW4,
     1DYW4
      COMMON/SECV/Y2,DY2,Y3,DY3,Y4,DY4,YB,DYB,D2YB,D2Y0,D2PHI,D2THETA,
     1D2YW2,D2YW3,D2YW4,DEL2,DEL3,DEL4,YSP2,YSP3,YSP4,YST2,YST3,YST4
      COMMON/FORCE/FV2,FV3,FV4,FH2,FH3,FH4,FY2,FSY3,FSY4,FX2,FSX3,FSX4,
     1FFS,FBS,FX34,FY34,WTR2,WTR3,WTR4
      COMMON/VEHCL/MH,IH,MB,IB,M2,M3,M4,L2,L3,S34,SFS,SBS,SB,A,HS,KSTOP,
     1SPEED,GG,HSTOP,STGAP
      COMMON/DYNAMIC/TIME,DTIME,FTIME,DER(12),JREAR,MM
      COMMON/TIRE/KT,BT,RAD,CONL,BS,AKC,A3C,PRESS,TLIM,TSTIF,ITIRE
C
C CALL SUBROUTINES TO DETERMINE THE FORCES ON VARIOUS
C VEHICLE COMPONENTS
      IF(ITIRE.NE.4)CALL POINTC
      IF(ITIRE.EQ.4)CALL ADORG
      CALL SUSP
      CALL BOGIE
C
      CTHETA=COS(THETA)
      CPHI=COS(PHI)
      STHETA=SIN(THETA)
      SPHI=SIN(PHI)
C
C**********************************************************************
C                   SYSTEM STATE EQUATIONS
C**********************************************************************
C
C THE STATE VARIABLES ARE***
C  (1) HULL PITCH ANGLE
C  (2) HULL PITCH VELOCITY
C  (3) BOGIE PITCH ANGLE
C  (4) BOGIE PITCH VELOCITY
C  (5) HULL HEAVE DISPLN
C  (6) HULL HEAVE VELOCITY
C  (7) FRONT AXLE DISPLN
C  (8) FRONT AXLE VELOCITY
C  (9) MIDDLE AXLE DISPLN
C  (10)MIDDLE AXLE VELOCITY
C  (11)REAR AXLE DISPLN
C  (12)REAR AXLE VELOCITY
      DER(1)=DTHETA
      DER(2)=2./IH*(FY34*(L3*CTHETA+(S34+GG)*STHETA)+FFS*((L3-SFS)*
     1CTHETA+GG*STHETA)+FBS*((L3+SBS)*CTHETA+GG*STHETA)-((S34+GG)*CTHETA
     1-L3*STHETA)*FX34-FY2*(L2*CTHETA-GG*STHETA)-FX2*(L2*STHETA+GG*
     2CTHETA))
      DER(3)=DPHI
      DER(4)=2./IB*(FSY4*A*CPHI           +FSX4*A*SPHI+FY34*SB*SPHI
     1-FX34*SB*CPHI           -FSY3*A*CPHI-FSX3*A*SPHI)
      DER(5)=DY0
      DER(6)=1./MH*(-MH*32.2+2.*(FY2+FY34+FFS+FBS))
      DER(7)=DYW2
      DER(8)=1./M2*(-M2*32.2+FV2-FY2)
      DER(9)=DYW3
      DER(10)=1./M3*(-M3*32.2+FV3-FSY3-FFS)
```

```
      DER(11)=DYW4
      DER(12)=1./M4*(-M4*32.2+FV4-FSY4-FBS)
C
C****************************************************************************
C
C DETERMINE VALUES OF VARIOUS ACCELERATIONS
      D2THETA=DER(2)
      D2PHI=DER(4)
      D2Y0=DER(6)
      D2YW2=DER(8)
      D2YW3=DER(10)
      D2YW4=DER(12)
      D2YB=D2Y0+L3*(-STHETA*DTHETA*DTHETA+CTHETA*D2THETA)+S34*(CTHETA*
     1DTHETA*DTHETA+STHETA*D2THETA)+S8*(CPHI*DPHI*DPHI+SPHI*D2PHI)
      RETURN
      END
```

```
      SUBROUTINE POINTC
C SUBROUTINE TO CALCULATE TIRE FORCES FOR THE FIRST THREE TIRE MODELS
      REAL MH,IH,MB,IB,M2,M3,M4,K2,K3,JN2,JN3,L2,L3,KSTOP,KT
      COMMON/STATE/THETA,DTHETA,PHI,DPHI,Y0,DY0,YW2,DYW2,YW3,DYW3,YW4,
     1DYW4
      COMMON/SECV/Y2,DY2,Y3,DY3,Y4,DY4,YB,DYB,D2YB,D2YG,D2PHI,D2THETA,
     1D2YW2,D2YW3,D2YW4,DEL2,DEL3,DEL4,YSP2,YSP3,YSP4,YST2,YST3,YST4
      COMMON/FORCE/FV2,FV3,FV4,FH2,FH3,FH4,FY2,FSY3,FSY4,FX2,FSX3,FSX4,
     1FFS,FBS,FX34,FY34,WTR2,WTR3,WTR4
      COMMON/VEHCL/MH,IH,MB,IB,M2,M3,M4,L2,L3,S34,SFS,SBS,SB,A,HS,KSTOP,
     1SPEED,GG,HSTOP,STGAP
      COMMON/DYNAMIC/TIME,DTIME,FTIME,DER(12),JREAR,MM
      COMMON/TIRE/KT,BT,RAD,CONL,BS,AKC,ABC,PRESS,TLIM,TSTIF,ITIRE
      COMMON/GRND/TER(500),OTER(500),DYX(500),ODYX(500),JMAX,MW,NW,XDEL
     1,YRMS
      COMMON/PHASE/IPHS,LPHS,KPHS,NXT,IXT,JSTP,JPHS
C
C TERRAIN ELEVATION AND RATE OF CHANGE OF ELEVATION
C UNDER EACH TIRE
      Y2=TER(KPHS+MW)
      Y3=TER(KPHS+NW)
      Y4=TER(KPHS)
      DY2=SPEED*DYX(KPHS+MW)
      DY3=SPEED*DYX(KPHS+NW)
      DY4=SPEED*DYX(KPHS)
C
C VERTICAL TIRE FORCES
      TDEF2=YST2+Y2-YW2
      TDEF3=YST3+Y3-YW3
      TDEF4=YST4+Y4-YW4
      FC2=TDEF2*KT+BT*(DY2-DYW2)
      FC3=2.*(KT*TDEF3+BT*(DY3-DYW3))
      FC4=2.*(KT*TDEF4+BT*(DY4-DYW4))
      IF(TDEF2.GE.TLIM)FC2=TLIM*KT+BT*(DY2-DYW2)+(TDEF2-TLIM)*KT*TSTIF
      IF(TDEF3.GE.TLIM)FC3=2.*(KT*TLIM+BT*(DY3-DYW3)+(TDEF3-TLIM)*KT*
     1TSTIF)
      IF(TDEF4.GE.TLIM)FC4=2.*(KT*TLIM+BT*(DY4-DYW4)+(TDEF4-TLIM)*KT*
     1TSTIF)
      FV2=FC2
      FV3=FC3
      FV4=FC4
      IF(FC2.LE.0.)FV2=0.
      IF(FC3.LE.0.)FV3=0.
      IF(FC4.LE.0.)FV4=0.
C
C HORIZONTAL TIRE FORCES
      FH2=-FV2*DYX(KPHS+MW)
      FH3=-FV3*DYX(KPHS+NW)
      FH4=-FV4*DYX(KPHS)
C
      RETURN
      END
```

```
      SYMBOLIC REFERENCE MAP (R=1)

ENTRY POINTS
    1  POINTC
```

```
      SUBROUTINE ADORG
C  THIS SUBROUTINE ORGANIZES CALCULATIONS OF THE THREE VERTICAL
C  AND THREE HORIZONTAL FORCES ACTING ON THE AXLES, USING
C  ADAPTIVE FOOTPRINT TIRE MODEL
      COMMON/ADMDL/ADDT,ADSDT,ADTH(40),ADDX(40),ADST(40),ADCT(40),
     1ADTT(40),NSG(40),NADS,NBACK,NAD2,ISCHEM,Y1,JGR,FXX,FYY,TLENT
     2,YI12,YI13,YI14,DYW,TERI2,TERI3,TERI4
      COMMON/SECV/Y2,DY2,Y3,DY3,Y4,DY4,YB,DYB,D2YB,D2Y0,D2PHI,D2THETA,
     1D2YW2,D2YW3,D2YW4,DEL2,DEL3,DEL4,YSP2,YSP3,YSP4,YST2,YST3,YST4
      COMMON/STATE/THETA,DTHETA,PHI,DPHI,Y0,DY0,YW2,DYW2,YW3,DYW3,YW4,
     1DYW4
      COMMON/FORCE/FV2,FV3,FV4,FH2,FH3,FH4,FY2,FSY3,FSY4,FX2,FSX3,FSX4,
     1FFS,FBS,FX34,FY34,WTR2,WTR3,WTR4
      COMMON/GRND/TER(500),OTER(500),DYX(500),ODYX(500),JMAX,MW,NW,XDEL
     1,YRMS
      COMMON/PHASE/IPHS,LPHS,KPHS,NXT,IXT,JSTP,JPHS
      DO 40 JADPT=1,3
      GO TO (10,11,12),JADPT
C FRONT TIRE
   10 YI1=YI12
      YW=YW2
      JGR=KPHS+MW
      Y2=TER(JGR)
      DYW=DYW2
      TERI=TERI2
      GO TO 13
C MIDDLE TIRES
   11 YI1=YI13
      YW=YW3
      JGR=KPHS+NW
      Y3=TER(JGR)
      DYW=DYW3
      TERI=TERI3
      GO TO 13
C REAR TIRES
   12 YI1=YI14
      YW=YW4
      JGR=KPHS
      Y4=TER(JGR)
      DYW=DYW4
      TERI=TERI4
   13 CONTINUE
C ALL TIRES
      Y1=YI1+YW-TERI
      CALL ADAPT
      GO TO (51,52,53),JADPT
C FRONT TIRE
   51 FV2=FYY
      FH2=FXX
      GO TO 54
C MIDDLE TIRES
C  MULTIPLY BY 2 , SINCE TWO TIRES ON MIDDLE AND BACK AXLES
   52 FV3=2.*FYY
      FH3=2.*FXX
      GO TO 54
C REAR TIRES
   53 FV4=2.*FYY
```

```
      FH4:2.*FXX
   54 CONTINUE
   40 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE ADAPT
C SUBROUTINE ADAPT DETERMINES FORCES ON A TIRE , GIVEN ITS
C POSITION ON THE PROFILE AND HEIGHT OF THE CENTER ABOVE THE REFERENCE
C PLANE. THE TIRE MODEL USED IS ADIPTIVE TIRE MODEL
C A CHOICE OF THREE ADAPTIVE MODELS OF VARYING DEGREE OF SOPHISTICATION
C IS AVAILABLE
C
C ISCHEM=0  THE FORCES ARE DETERMINED FROM APPROXIMATE GEOMETRICAL
C CONSIDERATIONS
C ISCHEM=1  THE GEOMETRICAL RELATIONS ARE MORE ACCURATE, BUT THE GROUND
C CONTACT LENGTH HAS TO BE CONTINUOUS AND THE BOTTOM POINT OF TIRE
C HAS TO BE ON CONTACT LINE
C ISCHEM=2 ELIMINATES THE ABOVE CONSTRAINTS
C
C THE SIMULATION COST INCREASES AS THE VALUE OF ISCHEM IS INCREASED
      COMMON/GRND/TER(500),OTER(500),DYX(500),ODYX(503),JMAX,MW,NW,XDEL
     1,YRMS
      COMMON/TIRE/KT,BT,RAD,CONL,BS,AKC,ABC,PRESS,TLIM,TSTIF,ITIRE
      COMMON/ADMDL/ADDT,ADSDT,ADTH(40),ADUX(40),ADST(40),ADCT(40),
     1ADTT(40),NSG(40),NADS,NBACK,NAD2,ISCHEM,Y1,JGR,FXX,FYY,TLENT
     2,YI12,YI13,YI14,DYW,TERI2,TERI3,TERI4
      COMMON/VEHCL/MH,IH,MB,IB,M2,M3,M4,L2,L3,S34,SFS,SBS,SB,A,HS,KSTOP,
     1SPEED,GG,HSTOP,STGAP
      DIMENSION FP(40),FKT(40),FNG(40),FHG(40),
     1DELR(40),DELTA(40),APHI(40),AL1(40),AL2(40),AL(40)
     2,ODEL(40),IDAMP(40),FBT(40)
      PI2=1.5708
      IBACK=0
C
C  CLEARING UP ARRAYS
      DO 20 K=1,NAD2
      DELTA(K)=0.
      DELR(K)=0.
      AL1(K)=0.
      AL2(K)=0.
      AL(K)=0.
      APHI(K)=0.
      ODEL(K)=0.
      IDAMP(K)=0
      FP(K)=0.
      FKT(K)=0.
      FBT(K)=0.
   20 CONTINUE
C***********************************************************************
C  GEOMETRIC CALCULATIONS
C***********************************************************************
      I=1
   37 JNOD=JGR+NSG(I)
      IF(JNOD.LT.2)JNOD=2
      APHI(I)=ATAN(DYX(JNOD))
      IF(IBACK.EQ.0)APHI(I)=ATAN(DYX(JNOD-1))
      IF(APHI(I).GT.PI2)APHI(I)=APHI(I)-3.14159
C
C DETERMINE VERTICAL AND RADIAL DEFLECTIONS
      DELTA(I)=RAD*ADCT(I)+TER(JNOD)-Y1
      ODEL(I)=(SPEED*DYX(JNOD)-DYW)/ADCT(I)
      IF(ISCHEM.EQ.0)GO TO 31
```

```
      IF(ABS(ABS(APHI(I)-ADTH(I))-PI2).LE.0.1)GO TO 31
      IF(ABS(ABS(APHI(I)-ADTH(I)+ADDT/2.)-PI2).LE.0.1)GO TO 31
      IF(ABS(ABS(APHI(I)-ADTH(I)-ADDT/2.)-PI2).LE.0.1)GO TO 31
      IF(I.EQ.1)DELR(I)=DELTA(I)
      IF(I.EQ.1)GO TO 33
      DELR(I)=ADDX(I)/ADST(I)+(DELTA(I)-ADDX(I)/ADTT(I))*
     1(ADCT(I)-ADST(I)*TAN(APHI(I)-ADTH(I)))
   33 IF(DELR(I).GT.0.0)IDAMP(I)=1
      IF(DELR(I).LE.0.0)GO TO 40
      IF(DELR(I).GT.RAD)GO TO 31
C
C DETERMINE CONTACT LENGTH
      AL1(I)=(RAD-DELR(I))*ADSDT/COS(APHI(I)-ADTH(I)-ADDT/2.)
      AL2(I)=(RAD-DELR(I))*ADSDT/COS(APHI(I)-ADTH(I)+ADDT/2.)
      IF(AL1(I).GT.DELR(I))GO TO 40
      IF(AL2(I).GT.DELR(I))GO TO 40
   44 AL(I)=AL1(I)+AL2(I)
      GO TO 35
C
C APPROXIMATE MODEL
   31 DELR(I)=DELTA(I)*ADCT(I)
      IF(DELR(I).LE.0.0)GO TO 34
      AL(I)=(RAD-DELR(I))*ADDT
      APHI(I)=ADTH(I)
C
   35 I=I+1
      IF(I.GT.NAD2)GO TO 36
      GO TO 37
C
C NO SECTOR GROUND CONTACT
   34 DELR(I)=0.
      AL(I)=0.
      IF(ISCHEM.EQ.2)GO TO 35
      IF(IBACK.EQ.1)GO TO 36
      IBACK=1
      I=NBACK
      GO TO 37
C
C PARTIAL CONTACT
   40 DIFPT=APHI(I)-ADTH(I)
      IF(ABS(DIFPT).LT.0.001.AND.DELR(I).LE.0.0)GO TO 34
      IF(ABS(DIFPT).LT.0.001.AND.DELR(I).GT.0.0)GO TO 44
      IF(DIFPT)41,41,42
   42 ZHS=DELR(I)/TAN(DIFPT)
      GO TO 43
   41 ZHS=DELR(I)/TAN(-DIFPT)
   43 YHS=ADDT*RAD/2.
      IF(ZHS.GT.YHS)GO TO 44
      AL(I)=(YHS+ZHS)/COS(DIFPT)
      IF(AL(I).LE.0.0)GO TO 34
      GO TO 35
   35 CONTINUE
C*************************************************************************
C  FORCE CALCULATIONS
C*************************************************************************
      FXX=0.
      FYY=0.
```

```
      TLENT=0.0
      DO 50 I=1,NAD2
      TLENT=TLENT+AL(I)
      FP(I)=BS*AL(I)*PRESS
      IF(FP(I).LE.0.0)FP(I)=0.0
      IF(DELR(I).LE.0.0)DELR(I)=0.0
      FKT(I)=AKC*ADDT*BS*(RAD*DELR(I)-DELR(I)*DELR(I)*0.5)
      IF(FKT(I).LE.0.0)FKT(I)=0.0
      IF(DELR(I).GE.TLIM)FKT(I)=AKC*ADDT*BS*(RAD*TLIM-TLIM*TLIM*0.5)
     1+TSTIF*AKC*ADDT*BS*(RAD-TLIM)*(DELR(I)-TLIM)
      FBT(I)=ABC*RAD*BS*ADDT*DDEL(I)*FLOAT(IDAMP(I))
      FNG(I)=FP(I)+(FKT(I)+FBT(I))*COS(APHI(I)-ADTH(I))
      IF(FNG(I).LE.0.0)FNG(I)=0.
      FHG(I)=(FKT(I)+FBT(I))*SIN(APHI(I)-ADTH(I))
      FYY=FYY+FNG(I)*COS(APHI(I))+FHG(I)*SIN(APHI(I))
      FXX=FXX-FNG(I)*SIN(APHI(I))+FHG(I)*COS(APHI(I))
   50 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SUSP
C SUBROUTINE TO CALCULATE SUSPENSION FORCES
      REAL MH,IH,MB,IB,M2,M3,M4,K2,K3,JN2,JN3,L2,L3,KSTOP,KT
      COMMON/STATE/THETA,DTHETA,PHI,DPHI,Y0,DY0,YW2,DYW2,YW3,DYW3,YW4,
     1DYW4
      COMMON/SECV/Y2,DY2,Y3,DY3,Y4,DY4,YB,DYB,D2YB,D2Y0,D2PHI,D2THETA,
     1D2YW2,D2YW3,D2YW4,DEL2,DEL3,DEL4,YSP2,YSP3,YSP4,YST2,YST3,YST4
      COMMON/FORCE/FV2,FV3,FV4,FH2,FH3,FH4,FY2,FSY3,FSY4,FX2,FSX3,FSX4,
     1FFS,FBS,FX34,FY34,WTR2,WTR3,WTR4
      COMMON/VEHCL/MH,IH,MB,IB,M2,M3,M4,L2,L3,S34,SFS,SBS,SB,A,HS,KSTOP,
     1SPEED,GG,HSTOP,STGAP
      COMMON/SPSV/K2,JN2,RB2,K3,JN3,RB3,SN,B2VJ,B2VR
      FRSF=0.05
      STHETA=SIN(THETA)
      CTHETA=COS(THETA)
      SPHI=SIN(PHI)
      CPHI=COS(PHI)
C***DISPLACEMENTS AND VELOCITIES OF SUSPENSION TOP ENDS
      YB=Y0+L3*STHETA+S34*(1.-CTHETA)+SB*(1.-CPHI)
      DYB=DY0+L3*CTHETA*DTHETA+S34*STHETA*DTHETA+SB*SPHI*DPHI
      YS2=Y0-L2*STHETA
      DYS2=DY0-L2*CTHETA*DTHETA
      YS3=YB-A*SPHI
      DYS3=DYB-A*CPHI*DPHI
      YS4=YB+A*SPHI
      DYS4=DYB+A*CPHI*DPHI
C***LEAF SPRING FORCES
      DEL2=YSP2+YW2-YS2
      DEL3=YSP3+YW3-YS3
      DEL4=YSP4+YW4-YS4
      DDEL2=DYW2-DYS2
      DDEL3=DYW3-DYS3
      DDEL4=DYW4-DYS4
      FK2=K2*DEL2
      FK3=K3*DEL3
      FK4=K3*DEL4
      SIGN=1.
      IF(DDEL2.LE.0.)SIGN=-1.
      FB2F=FRSF*K2*ABS(YW2-YS2)*SIGN
       SIGN=1.
      IF(DDEL3.LE.0.)SIGN=-1.
      FB3F=FRSF*K3*ABS(YW3-YS3)*SIGN
       SIGN=1.
      IF(DDEL4.LE.0.)SIGN=-1.
      FB4F=FRSF*K3*ABS(YW4-YS4)*SIGN
C***STOP CONTACT FORCES
      FSTOP2=0.
      IF(DEL2.GE.JN2)FSTOP2=(DEL2-JN2)*SN*K2
      IF(-DEL2.GE.RB2)FSTOP2=(DEL2+RB2)*SN*K2
      FSTOP3=0.
      IF(DEL3.GE.JN3)FSTOP3=(DEL3-JN3)*SN*K3
      IF(-DEL3.GE.RB3)FSTOP3=(DEL3+RB3)*SN*K3
      FSTOP4=0.
      IF(DEL4.GE.JN3)FSTOP4=(DEL4-JN3)*SN*K3
      IF(-DEL4.GE.RB3)FSTOP4=(DEL4+RB3)*SN*K3
C***VISCOUS DAMPER FORCE
      B2V=B2VJ
```

```
      IF(DDEL2.LE.0.0)B2V=B2VR
      FB2V=B2V*(DYW2-DYS2)
C**********TOTAL SUSPENSION FORCES
      FY2=FK2+FB2F+FB2V+FSTOP2
      FSY3=FK3+FB3F+FSTOP3
      FSY4=FK4+FB4F+FSTOP4
      FX2:FH2
      FSX3=FH3
      FSX4=FH4
      RETURN
      END
```

```
      SUBROUTINE BOGIE
C SUBROUTINE TO CALCULATE BOGIE AND STOP FORCES
      REAL MH,IH,MB,IB,M2,M3,M4,K2,K3,JN2,JN3,L2,L3,KSTOP,KT
      COMMON/STATE/THETA,DTHETA,PHI,DPHI,Y0,DYO,YW2,DYW2,YW3,DYW3,YW4,
     1DYW4
      COMMON/SECV/Y2,DY2,Y3,DY3,Y4,DY4,YB,DYB,D2YB,D2YG,D2PHI,D2THETA,
     1D2YW2,D2YW3,D2YW4,DEL2,DEL3,DEL4,YSP2,YSP3,YSP4,YST2,YST3,YST4
      COMMON/FORCE/FV2,FV3,FV4,FH2,FH3,FH4,FY2,FSY3,FSY4,FX2,FSX3,FSX4,
     1FFS,FBS,FX34,FY34,WTR2,WTR3,WTR4
      COMMON/VEHCL/MH,IH,MB,IB,M2,M3,M4,L2,L3,S34,SFS,SBS,SB,A,HS,KSTOP,
     1SPEED,GG,HSTOP,STGAP
      COMMON/SPSN/K2,JN2,RB2,K3,JN3,RB3,SN,B2VJ,B2VR
      CTHETA=COS(THETA)
      CPHI=COS(PHI)
      STHETA=SIN(THETA)
      SPHI=SIN(PHI)
C
C STOP FORCES
      GB=SBS*(THETA-PHI)+STGAP-DEL4
      GF=SFS*(PHI-THETA)+STGAP-DEL3
      FFS=0.
      FBS=0.
      IF(GF.LE.0.0.AND.ABS(GF).LT.HS)FFS=-KSTOP*GF*K3
      IF(GF.LE.0.0.AND.ABS(GF).GE.HS)FFS=-HSTOP*K3*(HS+GF)+KSTOP*K3*HS
      IF(GB.LE.0.0.AND.ABS(GB).LT.HS)FBS=-KSTOP*GB*K3
      IF(GB.LE.0.0.AND.ABS(GB).GE.HS)FBS=-HSTOP*K3*(HS+GB)+KSTOP*K3*HS
C
C
C BOGIE FORCES
      FX34=FSX3+FSX4
      XA=-MH*32.2+2.*(FY2+FFS+FBS)
      XB=L3*CTHETA+(S34+GG)*STHETA
      XC=FFS*((L3-SFS)*CTHETA+GG*STHETA)+FBS*((L3+SBS)*CTHETA+GG*STHETA)
     1-((S34+GG)*CTHETA-L3*STHETA)*FX34-FY2*(L2*CTHETA-GG*STHETA)
     2-FX2*(L2*STHETA+GG*CTHETA)
      XD=FSY3+FSY4-MB*32.2/2.
      XE=SB*SPHI
      XF=FSY4*A*CPHI+FSX4*A*SPHI-FX34*SB*CPHI-FSY3*A*CPHI-FSX3*A*SPHI
      XG=L3*CTHETA+S34*STHETA+GG*STHETA
      XH=SB*SPHI
      XI=-L3*STHETA*DTHETA*DTHETA+S34*CTHETA*DTHETA*DTHETA+SB*CPHI*DPHI
     1*DPHI+GG*CTHETA*DTHETA*DTHETA
      FY34=(2.*XD/MB-XA/MH-2.*XG*XC/IH-2.*XH*XF/IB-XI)
     1/(2.*XG*XB/IH+2.*XH*XE/IB+2./MH+2./MB)
      RETURN
      END
```

```
      SUBROUTINE PSTORE
C SUBROUTINE TO STORE SELECTED VARIABLES FOR PLOTTING
      COMMON/STATE/THETA,DTHETA,PHI,DPHI,Y0,DY0,YW2,DYW2,YW3,DYW3,YW4,
     1DYW4
      COMMON/SECV/Y2,DY2,Y3,DY3,Y4,DY4,YB,DYB,D2YB,D2Y0,D2PHI,D2THETA,
     1D2YW2,D2YW3,D2YW4,DEL2,DEL3,DEL4,YSP2,YSP3,YSP4,YST2,YST3,YST4
      COMMON/FORCE/FV2,FV3,FV4,FH2,FH3,FH4,FY2,FSY3,FSY4,FX2,FSX3,FSX4,
     1FFS,FBS,FX34,FY34,WTR2,WTR3,WTR4
      COMMON/DYNAMIC/TIME,DTIME,FTIME,DER(12),JREAR,MM
      COMMON/XYPLT/NPLTM,NPLT(10),PLT(10,500),XREAR,JPL,IXAX
     1,PLSTR,PLSTP,LIMP
      COMMON/GRND/TER(500),OTER(500),DYX(500),DDYX(500),JMAX,MW,NW,XDEL
     1,YRMS
      COMMON/PHASE/IPHS,LPHS,KPHS,NXT,IXT,JSTP,JPHS
      DIMENSION YPLT(40)
      YPLT(1)=THETA*180./3.14159
      YPLT(2)=DTHETA*180./3.14159
      YPLT(3)=PHI*180./3.14159
      YPLT(4)=DPHI*180./3.14159
      YPLT(5)=Y0
      YPLT(6)=DY0
      YPLT(7)=YW2
      YPLT(8)=DYW2
      YPLT(9)=YW3
      YPLT(10)=DYW3
      YPLT(11)=YW4
      YPLT(12)=DYW4
      YPLT(13)=FV2/WTR2
      YPLT(14)=FV3/WTR3/2.
      YPLT(15)=FV4/WTR4/2.
      YPLT(16)=FH2/WTR2
      YPLT(17)=FH3/WTR3/2.
      YPLT(18)=FH4/WTR4/2.
      YPLT(19)=FY2
      YPLT(20)=FSY3
      YPLT(21)=FSY4
      YPLT(22)=Y2
      YPLT(23)=Y3
      YPLT(24)=Y4
      YPLT(25)=YB
      YPLT(25)=D2Y0
      YPLT(27)=DEL2
      YPLT(28)=DEL3
      YPLT(29)=DEL4
      YPLT(30)=OTER(KPHS)
      YPLT(31)=TER(KPHS)
      DO 11 J=1,NPLTM
      MP=NPLT(J)
      PLT(J,IXT)=YPLT(MP)
   11 CONTINUE
      PLT(9,IXT)=XREAR
      IF(IXAX.EQ.1)PLT(9,IXT)=TIME
      RETURN
      END
```

```
      SUBROUTINE VPLOTS(IPLN)
C PLOTTING SUBROUTINE
      COMMON/XYPLT/NPLTM,NPLT(10),PLT(10,500),XREAR,JPL,IXAX
     1,PLSTR,PLSTP,LIMP
      DIMENSION A(500),B(500)
      YPN=FLOAT(NPLT(IPLN))
      JPL1=JPL+1
      JPL2=JPL+2
      DO 10 I=1,JPL
      A(I)=PLT(IPLN,I)
   10 CONTINUE
      CALL SCALE(A,6.0,JPL,1)
      IF(IPLN.GT.1)GO TO 11
      DO 12 I=1,JPL
      B(I)=PLT(9,I)
   12 CONTINUE
      CALL SCALE(B,5.,JPL,1)
   11 CONTINUE
      IF(IXAX.EQ.1)CALL AXIS(0.,0.,4HTIME,-4,5.,0.,B(JPL1),B(JPL2))
      IF(IXAX.EQ.0)CALL AXIS(0.,0.,8HX DISPLN,-8,5.,0.,B(JPL1),B(JPL2))
      CALL AXIS(0.,0.,8HVARIABLE,8,6.,90.,A(JPL1),A(JPL2))
      CALL NUMBER(-0.25,4.5,.14,YPN,90.,-1)
      CALL LINE(B,A,JPL,1,0,0)
      CALL PLOT(3.,0.,-3)
      RETURN
      END
```

```
      SUBROUTINE IOLAB(JS)
C READ AND PRINT HEADER CARD
      COMMON/IONUM/NWT,NRD,LABEL(80)
      DO 100 I=1,JS
      READ(NRD,9011)(LABEL(K),K=1,80)
      WRITE(NWT,9006)(LABEL(K),K=1,80)
  100 CONTINUE
 9011 FORMAT(80A1)
 9006 FORMAT(20X,80A1)
      RETURN
      END
```

```
SUBROUTINE IOLABD       74/74    OPT=1                          FTN 4.6+433          01/10/78  11.03.54        PAGE      1

                SUBROUTINE IOLABD(DATA)
          C READ AND PRINT REAL DATA CARD
                COMMON/IONJM/NWT,NRD,LABEL(80)
                READ(NRD,9010)(LABEL(K),K=1,30),DATA,(LABEL(J),J=31,42)
                WRITE(NWT,9000)(LABEL(K),K=1,30),DATA,(LABEL(J),J=31,42)
           9010 FORMAT(30A1,F10.4,12A1)
           9000 FORMAT(38X,30A1,3H : ,F12.3,2X,12A1)
                RETURN
                END
```

```
      SUBROUTINE IOLAB2(JS)
C READ AND PRINT WITH A LINE SKIP
      COMMON/IONUM/NWT,NRD,LABEL(80)
      DO 100 K=1,JS
      READ(NRD,9011)(LABEL(I),I=1,80)
      WRITE(NWT,9007)(LABEL(I),I=1,80)
  100 CONTINUE
 9011 FORMAT(80A1)
 9007 FORMAT(20X,80A1,/)
      RETURN
      END
```

APPENDIX B

DETAILS OF THE CONTROL SYSTEM

Details of the control system software included in this appendix supplement the discussion in Chapter 3.

B.1 Principal Nomenclature

A/D	- Analog to digital converter. A hardware input device which converts analog voltages to digital (binary) number for computer utilization.
ASCII	- American standard code for information interchange. A binary coding standard for representing characters and symbols in digital form.
Console Device	- An I/O device which is the normal operating system communication channel between the user and the computer.
Core Image	- The binary version of a program in a form that the computer can directly execute.
CPU	- Central Processing Unit. The hardware in a computer that controls system operation and performs logical and arithmetic operations.
D/A	- Digital to Analog converter. A hardware output device which converts digital (binary) numbers into analog voltages.
DAM	- Digital to Analog Multiplier. A special type of D/A which multiplies a D/A output by an analog voltage reference.
Data Switches (Sense Switches)	- A group of eight switches on the computer front panel which can be set on or off and tested by the computer for logical processes. (See Figure 11.)
DMAC	- Direct Memory Access Channel. A hardware device which allows high speed (one million words/second) transfer of data to and from the computer memory without effecting the CPU.
EAI	- Electronic Associates Incorporated. Company which supplied the hardware for the control system.

EOF - End of File. A code which the computer recognizes as the end of a set of data.

EOR - End of Record. A code which the computer recognizes as the end of a discrete record in a set of data.

FILE - A set of data, blocked into records and terminated by an EOF, stored on a disk. The file is identified by a file name and may contain programs or data.

I/O - Input-output.

K - Symbol for binary one thousand, 1024.

Logical Unit - A logical unit number (octal) associated with a data set or an I/O device.

Monitor - Supervisor program which controls system resources and utility program operation. Decodes user commands to execute operating system function.

Object Code - Binary code produced by the FORTRAN compiler or ASSEMBLER. The object code is input by the loader and linked together to create a core image file.

Octal - A base eight number system.

Operating System - (See Monitor)

Record - A physical or logical partition of data for input or output. Typical block of data read or written during one I/O operation.

Source - Program code written by the user for input to the compiler or assembler.

 - Carriage return character.

B.2 Computer Programs

The control system software incorporates two programs: (a) file builder program, and (b) control program. These programs are described in the following.

B.2.1 File Builder Program

This program reads the paper tapes containing the axle displacement records, packs the data in a buffer and writes them on a disc file, as shown in Figure 9(a). The flow chart of the program is given in Figure B-1.

B.2.1.1 Listing

The file builder program is coded in EAI FORTRAN, and a listing of the program appears on the following pages.

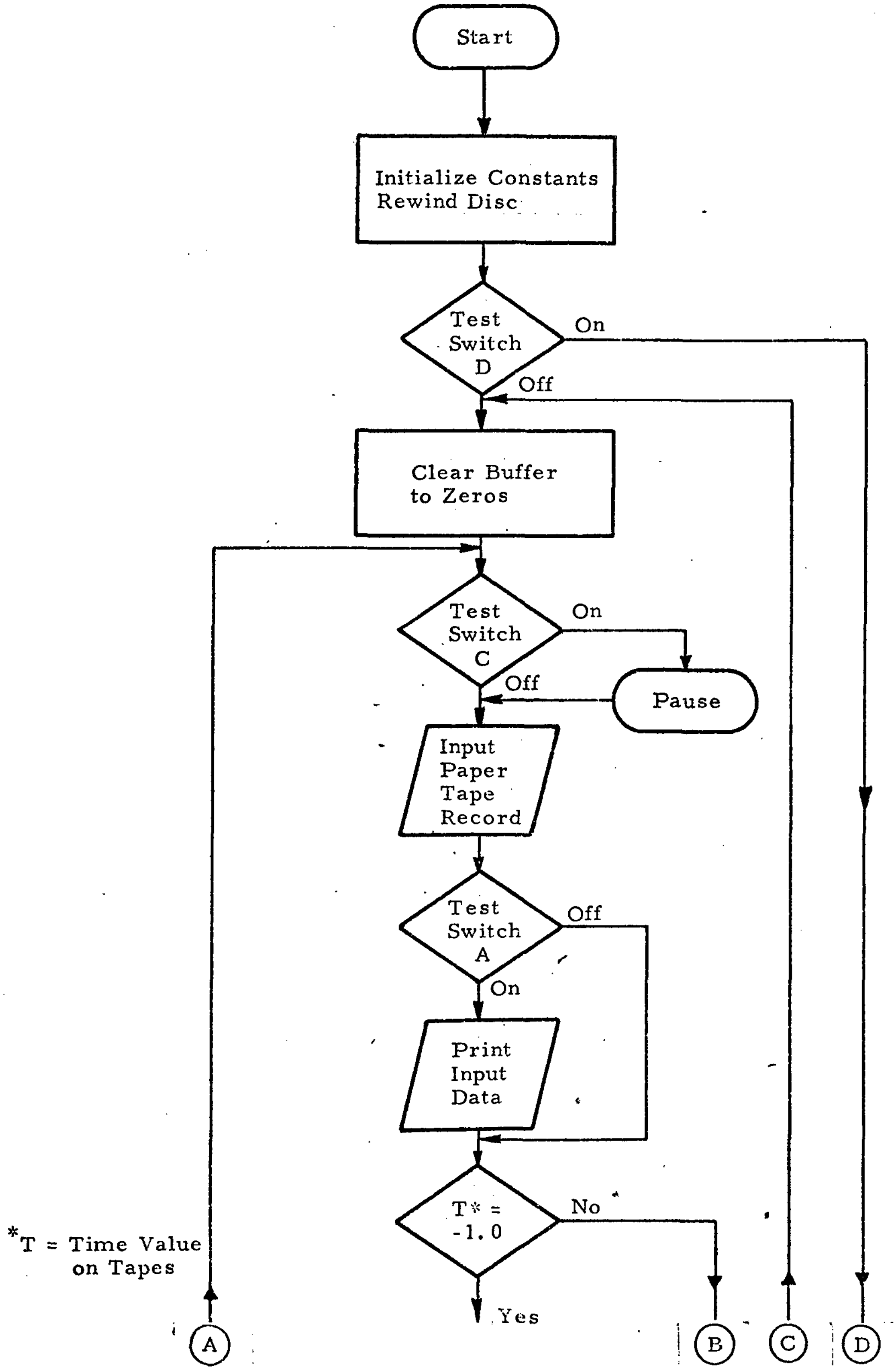


Figure B-1. File Builder Program Flow Chart

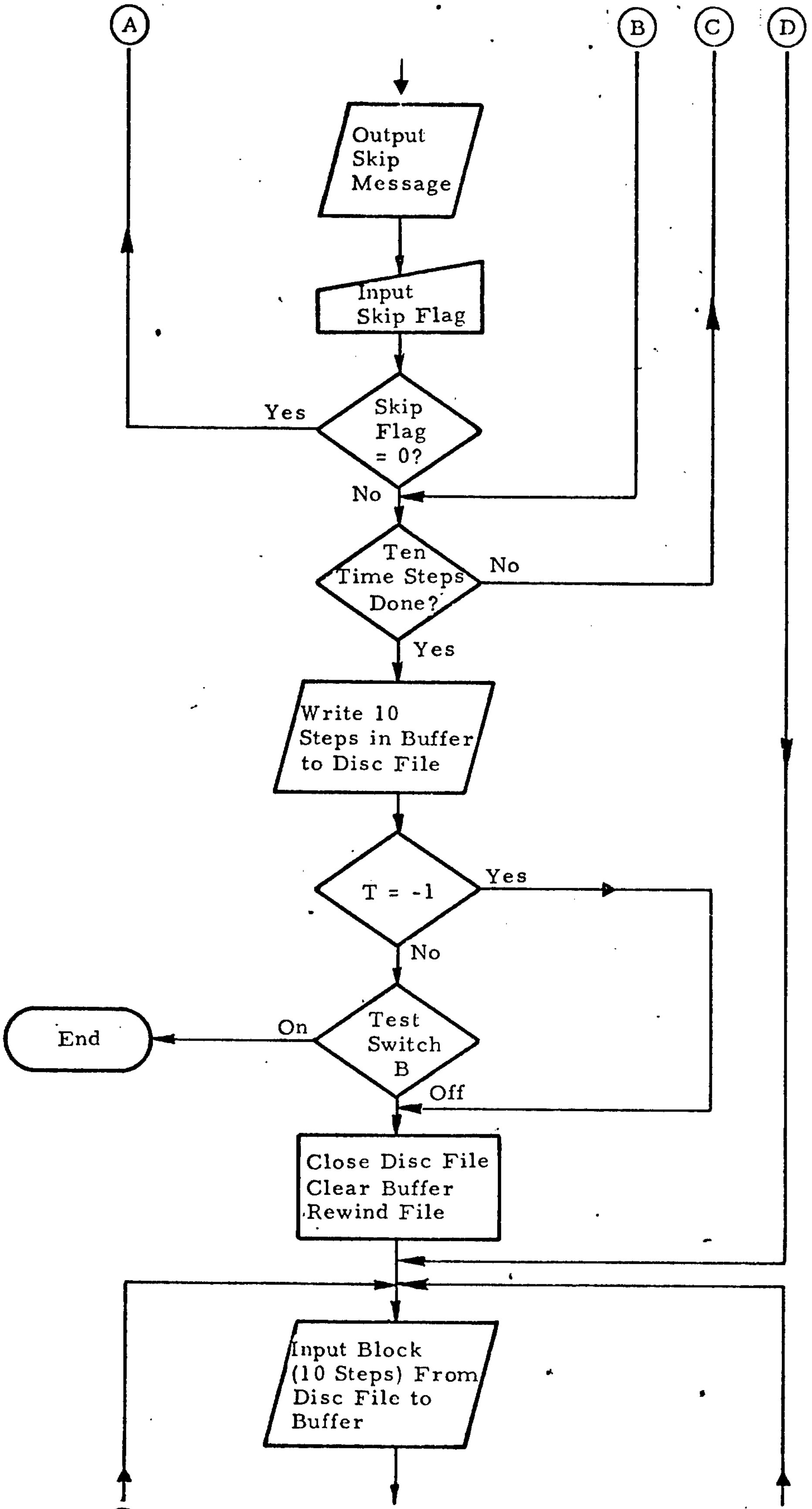


Figure B-1. File Builder Program Flow Chart (Cont)

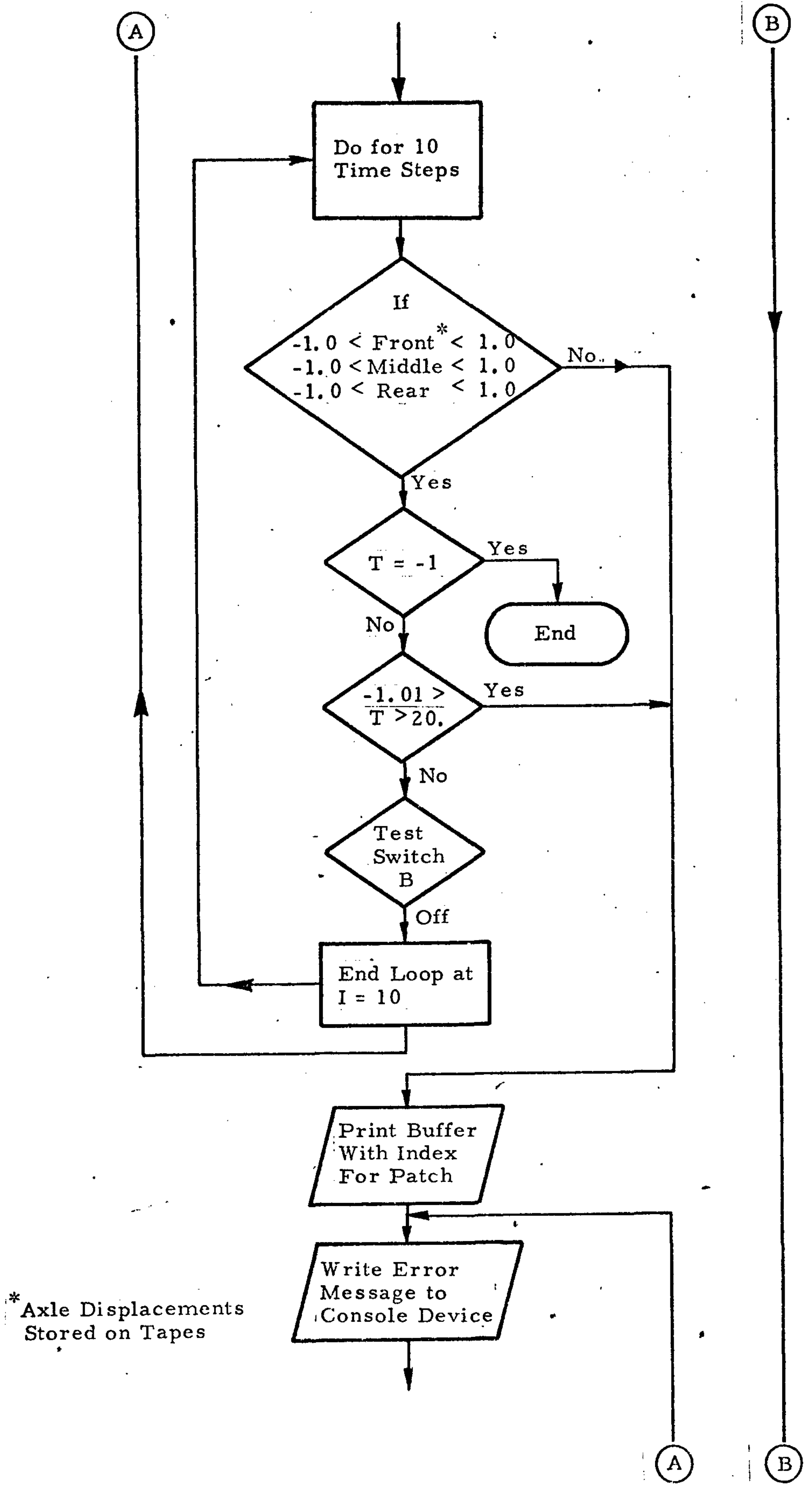


Figure B-1. File Builder Program Flow Chart (Cont)

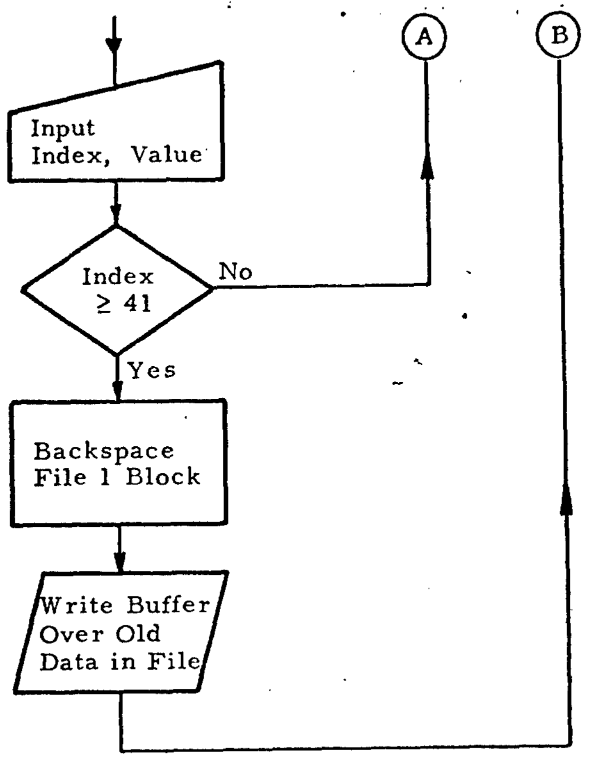


Figure B-1. File Builder Program Flow Chart (Cont)

```
C FILE BUILDER PROGRAM
C INPUT PAPER TAPE DATA TO DISK/PRINT,AND FILE PATCHER
C DATA ON PAPER TAPE IS TEN TIME STEPS PER RECORD ON DISK
C -1.0 IN TIME SLOT MARKS END OF DATA SET
C PROGRAM REQUIRES LOGICAL UNIT 21 OCTAL BE POSITIONED TO DATA SET
C DATA SWITCHES A,B,C,D USED FOR PROGRAM CONTROL
C A ON PRINTS INPUT TAPE AS READ
C B ON ENDS PROGRAM,ABNORMAL EXIT
C C ON PAUSE PROGRAM BEFORE TAPE RECORD INPUT,EACH RECORD = 1 STEP
C D ON SKIPS TAPE INPUT AND LINKS TO SCANNER SECTION
C DISK I/O DONE VIA QMOND CALLS,44 ELEMENTS PER RECORD
C LAST LINE OF RECORD IS ZERO
      DIMENSION BUFF(120)
      LOGICAL SENSW
      NINP=2
      NTYP=1
      NDISK=17
C OCTAL 21
      NPRNT=16
      NTAPE=4
      WRITE(NTYP,9300)
9300  FORMAT(5X,22H FILE CREATION PROGRAM,/,
     1 22H SET DATA SWITCHES A-D,/,
     2 32H HIT CARRIAGE RETURN TO EXECUTE.,/)
      READ(NINP,9350)
9350  FORMAT(1X)
      REWIND NDISK
      IF(SENSW(4)) GO TO 2100
      DO 1000 I=1,10000
C CLEAR BUFFER TO ZERO
      DO 50 J=1,50
      BUFF(J)=0.0
50    CONTINUE
      DO 100 J=1,10
      K1=(J-1)*4+1
      K2=K1+3
75    IGO=1
      IF(SENSW(3)) PAUSE
      READ(NTAPE,9000)(BUFF(IJK),IJK=K1,K2)
9000  FORMAT(F7.4,3F8.5)
      IF(SENSW(1))WRITE(NPRNT,9500)(BUFF(IJK),IJK=K1,K2)
9500  FORMAT(5X,4F15.5)
      IF(BUFF(K1).NE.-1.0) GO TO 100
      WRITE(NTYP,9010)
9010  FORMAT(5X,31H -1 INPUT,TYPE 0 TO SKIP,ELSE 1,/)
      READ(NINP,9020)IGO
9020  FORMAT(I1)
      IF(IGO.EQ.0) GO TO 75
100   CONTINUE
C DUMP DATA BUFFER TO DISK
      CALL QMOND(16,NDISK,BUFF(1),BUFF(44))
      IF(BUFF(K1).EQ.-1.0) GO TO 2000
      IF(SENSW(2)) GO TO 3000
1000   CONTINUE
C END FILE ,CLOSE UNIT
2000  ENDFILE NDISK
```

```
C REWIND AND TEST FILE
      DO 2025 I=1,44
2025   BUFF(I)=0.0
2050  REWIND NDISK
2100  CALL QMOND(17,NDISK,BUFF(1),BUFF(44))
C TEST DATA TO LOOK FOR BAD POINTS
      DO 2200 I=2,40,4
      IF((BUFF(I).GT.1.0).OR.(BUFF(I).LT.-1.0)) GO TO 2300
      IF((BUFF(I+1).GT.1.0).OR.(BUFF(I+1).LT.-1.0)) GO TO 2300
      IF((BUFF(I+2).GT.1.0).OR.(BUFF(I+2).LT.-1.0)) GO TO 2300
      IF(BUFF(I-1).EQ.-1.0) GO TO 3000
      IF((BUFF(I-1).LT.-1.01).OR.(BUFF(I-1).GT.20.0)) GO TO 2300
      IF(SENSW(2)) GO TO 3000
2200  CONTINUE
      GO TO 2100
2300  WRITE(NPRNT,9100)(I,BUFF(I),I=1,40)
9100  FORMAT(4(2X,I2,2X,E12.5))
2400  WRITE(NTYP,9220)
9220  FORMAT(54H INPUT ID = TO BUFFER TO CHANGE AND NEW VALUE,I2E12.5   ,
     1 /,16H ID .GE.41 STOPS ,/)
      READ(NINP,9210)ID,BUFF(ID)
9210  FORMAT(I2,E12.5)
      IF(ID.GE.41) GO TO 2450
      GO TO 2400
2450  BACKSPACE NDISK
      CALL QMOND(16,NDISK,BUFF(1),BUFF(44))
      GO TO 2100
3000  CONTINUE
      CALL EXIT
      END
```

B.2.2 Control Program

The control program transfers the axle displacement records from a disc storage file to the digital to analog converters as shown in Figure 9(b). The records are synchronized by a crystal controlled real time clock prior to the transmission. Figure B-2 shows a flow chart of the program.

B.2.2.1 Listing

An EAI FORTRAN listing of the program appears in the pages following the flow chart.

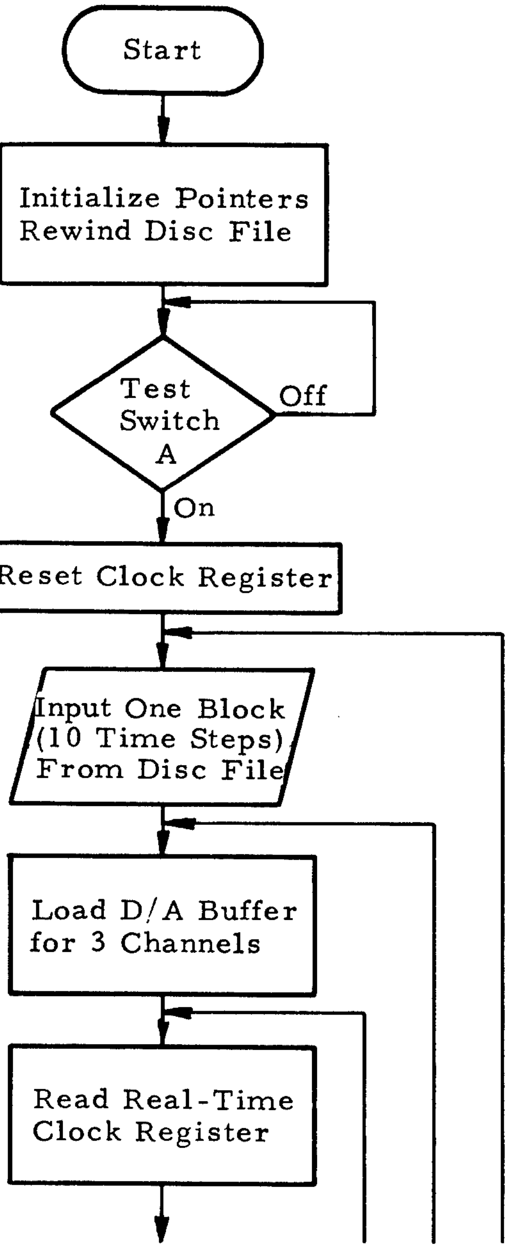


Figure B-2. Control Program Flow Chart

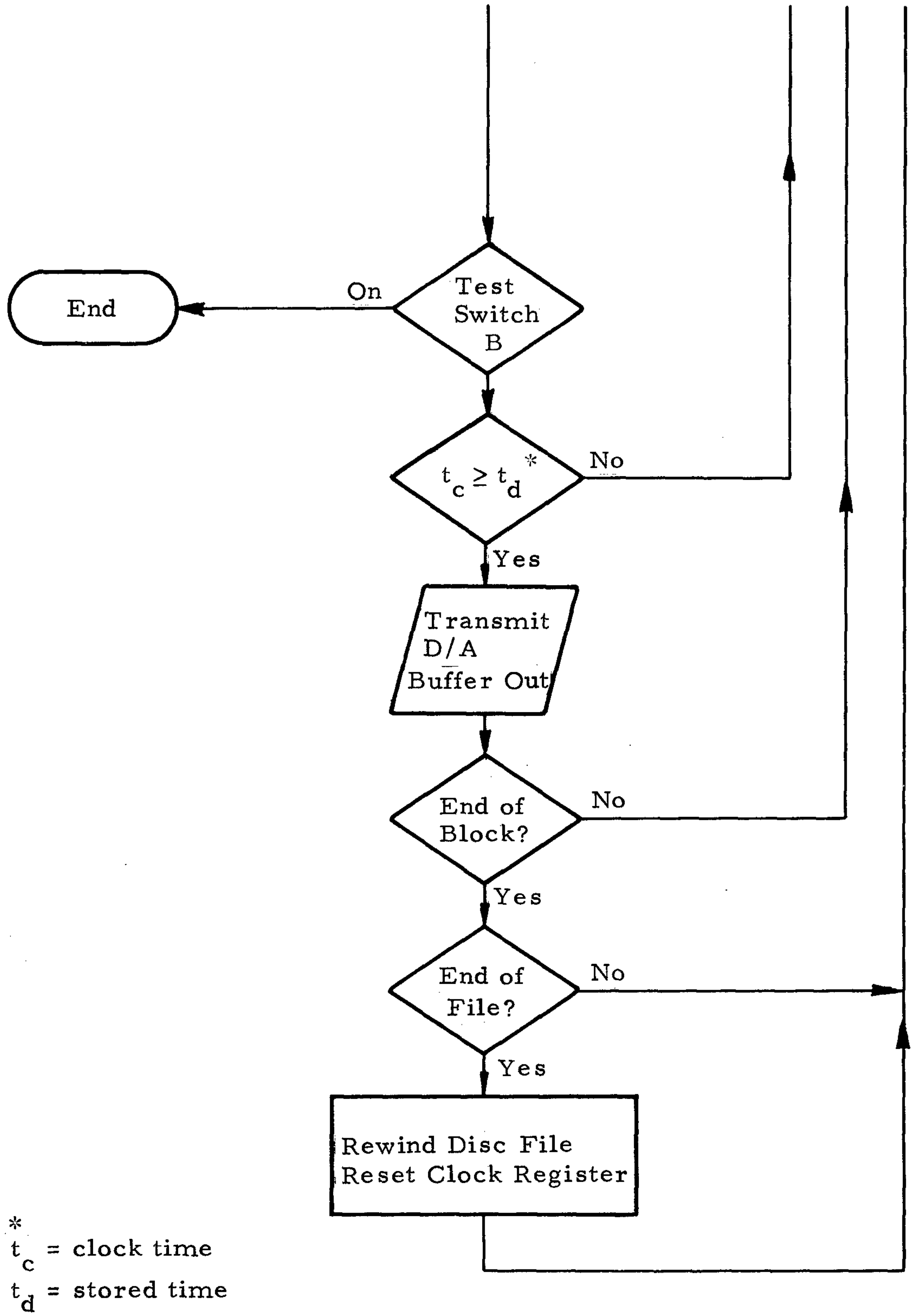


Figure B-2. Control Program Flow Chart (Cont)

```
C TRUCK SHAKER PROGRAM
C INPUT DATA FILE MUST BE POSITIONED TO LOGICAL UNIT 21 TO RUN
      DIMENSION XBUFF(100),ZERO(10)
      LOGICAL SENSW
      DATA ZERO/0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0/
      CALL QSHYIN(IERR,580)
      NDISK=17
C EQUALS OCTAL 21
      NTYP=1
      NINP=2
      WRITE(NTYP,9001)
9001  FORMAT(15H PROGRAM SHAKER,/,21H LU =21 FOR DATA FILE    )
      REWIND NDISK
C SET INTERVAL TIMER TO 30 SECONDS
      TIME=30000.0
      CALL QWTIMR(TIME,IERR)
C ONE SECTOR = 88 16 BIT WORDS,OF 11 TIME STEPS,BUT 10/RECORD USED
C INPUT ONE SECTOR TO XBUFF
      CALL QMOND(17,NDISK,XBUFF(1),XBUFF(44))
C INITIALIZE POINTERS
      IPNT=1
      INC=4
      NSTEP=10
C SET D/A LINES TO ZERO
      CALL QWBDAR(ZERO,0,7,IERR)
      CALL QSTDA
C DISABLE ERROR MESSAGES AND WAIT FOR SW 1 TO GO ON,TRUE
      CALL QUIET
C CALL LOW SPEED WAIT
50    CALL QSDLY(1000)
C START TRANSMISSION WHEN SENSW 1 TRUE,ON
      IF(SENSW(1)) GO TO 75
      GO TO 50
75    CALL QWTIMR(TIME,IERR)
C SYNC TO PROGRAM AND CLOCK
100   DO 200 I=1,NSTEP
C TEST FOR EOF
      IF(XBUFF(IPNT).EQ.-1.0) GO TO 300
C LOAD D/A BUFFER WITH DATA
      CALL QWBDAR(XBUFF(IPNT+1),1,3,IERR)
C WAIT FOR STEP
      XTIME=XBUFF(IPNT)*1000.0
150   CALL QRTIMR(RTIME,IERR)
      IF(TIME-RTIME-XTIME)150,160,160
C AFTER CLOCK SYNC TRANSMIT DATA OUT D/A LINES
160   CALL QSTDA
      IPNT=IPNT+INC
C TEST SENSW 2 FOR END PROGRAM
      IF(SENSW(2)) GO TO 5000
200   CONTINUE
C GET NEXT RECORD FROM DISK
210   CALL QMOND(17,NDISK,XBUFF(1),XBUFF(44))
      IPNT=1
      GO TO 100
C END OF DATA,REWIND DISK AND RESTART
300   REWIND NDISK
```

```
      CALL QWTIMR(TIME,IERR)
      IREC=0
      GO TO 210
C PROGRAM END ON SENSW , LINK BACK TO MONITOR
5000   WRITE(NTYP,9010)
9010  FORMAT(12H END PROGRAM )
      CALL EXIT
      END
```

B.3 Program Generation Details

How to create a core image version of a program is explained in this section. Several details of the operation are not included in the description because they are readily available in the EAI reference manuals (reference 4, 5, 6 and 7). The core image is generated according to the following three steps:

a. Creation of source program file with BASIC TEXT EDITOR program

b. Compilation of source program using the FORTRAN compiler

c. Generation of core image file with CORE IMAGE GENERATOR program.

A diagram of the process is shown in Figure B-3.

B.3.1 Source File Generation

The source file creation step requires a number of operations by the user. First, the source input is punched on paper tape in a form required by the text editor. (See reference 6.) Then the disk file for the source storage is created with a monitor command, and the Basic Text Editor is loaded and executed. The complete procedure is outlined below:

```
#N, SOURCE, 22, 0
```

where

#N	=	create file entry command
SOURCE	=	file name
22	=	logical unit number of file opened, octal
0	=	identifies source file type.

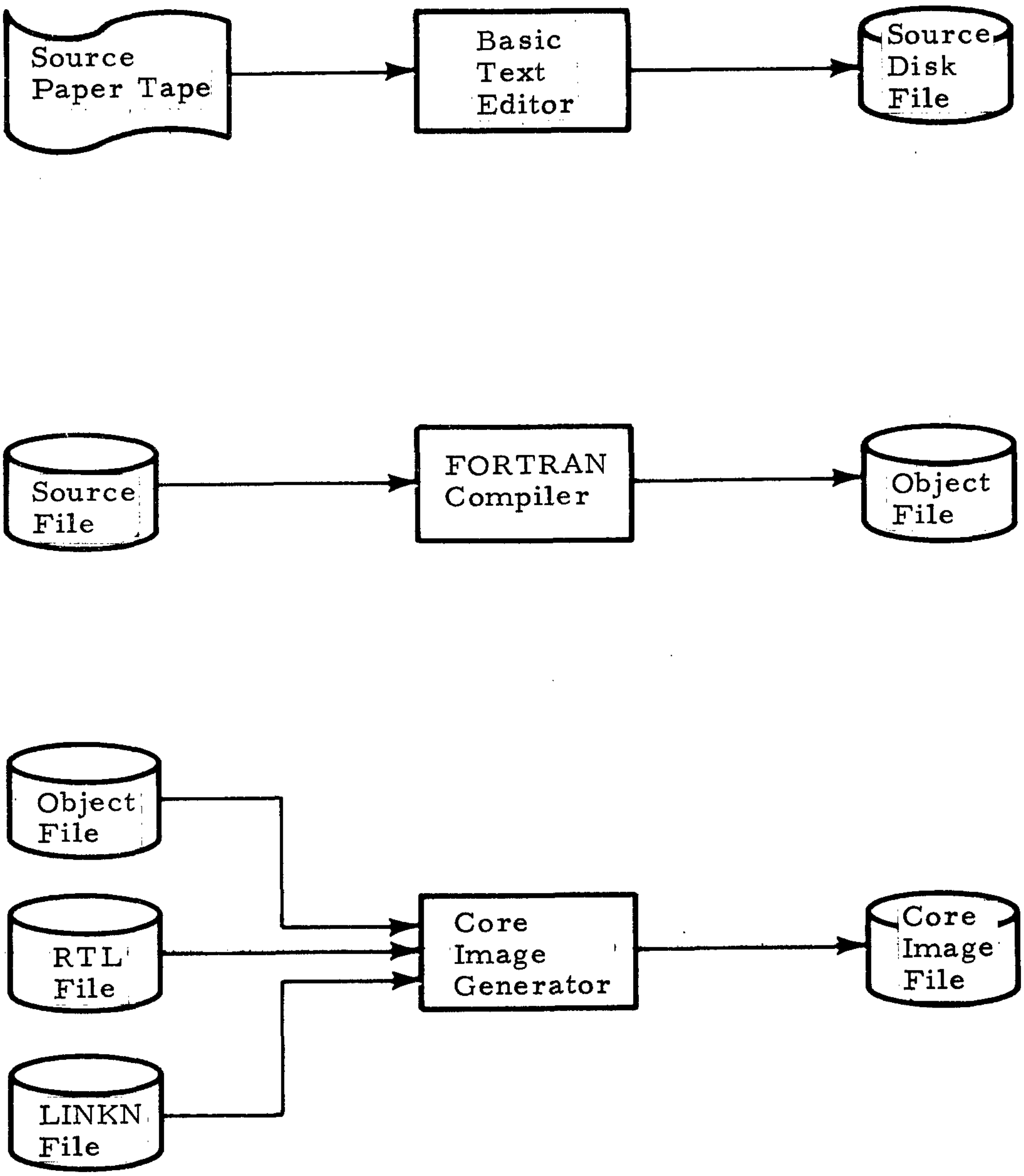


Figure B-3. Program Generation Sequence

#L, BTE, 21 ↵

where

#L = load file command
BTE = file name of basic text editor
21 = logical unit number for loader.

#R, 220, 422, 17777 ↵

where

#R = set hardware register command
220 = command input = console and list output = printer
422 = text input = paper tape and text output = disc
17777 = buffer memory space (see reference 6).

#G, 1000 ↵

NNN, B ↵	input NNN lines of program
W ↵	write buffer to disc file
F ↵	write end of file mark
M ↵	return to monitor.

If changes in the source code from the paper tape version are required they would be done with the editor before the write (W ↵) instruction. (See reference 6.)

B.3.2 Program Compilation

The FORTRAN compiler inputs code from the previously created source file and creates an object file which the program loader requires. An object file for the compiler output must be created before execution.

Example #N, OBJECT, 23, 1 ↵

where

#N = create disc file
OBJECT = name of object file
23 = logical unit for compiler output
1 = identifies object file type.

#P, SOURCE, 22 ↵

where

#P = open disc file
SOURCE = file name from text editor output
22 = logical unit number for source input.

#L, FORTR, 21 ↵ (FORTR = compiler file name)
#R, , 20702, 41162 ↵

where

#R = register set command
20702 = non-standard compiler options
41162 = source, object, list logical units. (See reference 4)

#G, 1000 ↵

If the program compiles correctly, the object file OBJECT is ready for input by the core image generator.

B.3.3 Core Image Generation

The core image generator takes the user's object file and links it with the required system subroutines. However, before initiating the process, an output file must be created and the object file positioned:

Example #N, CORIMG, 23, 2

where

#N	=	file creation command
CORIMG	=	file name of core image
23	=	logical unit file opened on
2	=	identifier for CI file type.

#P, OBJECT, 22

where

#P	=	command to open disc file
OBJECT	=	name of object input file
22	=	logical unit number of file.

#L, CIG, 21

where

#L	=	loader command
CIG	=	file name of Core Image Generator
21	=	logical unit number for loader.

#R, , 101000, 23000 ↵

where

#R	=	register setting command
101000	=	non-standard options, standard execution address
23000	=	logical unit output = 23, zone zero starts at 000

#G, 1000 ↵	execute
#F, OBJECT, 22 ↵	force load object file to output
#L, LINKN, 24 ↵	library load (selective) required subroutines from hybrid linkage library
# L, RTL, 24 ↵	library load (selective) required subroutines from run time library
#M ↵	close file on disc and return to monitor.

The program can now be loaded from disc and executed with a single load command as described in 3.2.

B.4 Data Storage Formats

Axle displacement records are obtained by the system from paper tapes punched in ASCII standard eight level tape format. Corresponding to each time step, there are four elements punched on the tape, i.e., the time value (seconds), front axle displacement (feet), middle axle displacement (feet), and the rear axle displacement (feet). These data are in FORTRAN format F7.4, 3F8.5 (see 2.2.2.3), therefore, typical data look like:

Example 01.2345, Time
+0.12345, Front axle
-0.98765, Middle axle
+0.34567, Rear axle

Counting the characters in the above show that each time step requires 31 frames of paper tape. These values are stored in memory and on disc as 32 bit real numbers, therefore, data for each time step require eight 16-bit words of storage (specific details on storage can be found in EAI publications, i.e., references 4, 5, 6 and 7).

When these data are transferred to a disc storage* file they are formatted such that each sector (largest block of data that can be transferred in one operation) is 88 16-bit words. This allows up to 11 time steps to be packed into each sector. The program actually stores 10 time steps or 40 values, with four zeros at the end to fill up the sector.

```
Example   1    00.0000 + 0.12345 - 0.98765 + 0.34567  )
          2    00.0039 + 0.12201 - 0.98321 + 0.34921  |
          .       .                                   |
          .       .                                   |  One
          .       .                                   |  Sector
          10   00.0451 + 0.10310 - 0.93415 + 0.39216  |
          11   00.0000 00.00000 00.00000 00.00000     |
             EOR                                      )
```

*Input/output with disc storage is carried out by calls to the monitor by a system routine QMOND, details of which are available in reference 4.

The full data file then consists of a chain of blocks, 10 steps each, with the final block containing -1.0 fill up elements to the EOR.

Example

```
          .
          .
          .
        EOR
        18.0000 + 1.00000 - 0.01023 + 0.97510
          .
          .
          .
        0.0       0.0       0.0       0.0
        EOR
        18.0040 + 0.95610 - 0.020501 + 0.96321
          .
          .
          .
        -1.0000 - 1.00000 - 1.00000 - 1.00000  }  Marks end
        -1.0000 - 1.00000 - 1.00000 - 1.00000  }  of file
        EOR
        EOF (End of Disc File)
```

Employing -1 indicators allows file lengths to be changed without altering the programs, as long as the end of the file is marked by a series of -1.0.

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6. Anon., "Pacer 100 Applications Programming Manual", EAI, West Long Branch, New Jersey

7. Anon., "Pacer 100 Library and Utility Manual", EAI, West Long Branch, New Jersey

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Shake Testing

Vehicle Simulation

Tire Models

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

Recorded simulation control scheme is a method of generating realistic inputs for vehicle shake tests. The scheme involves generating axle displacement records by simulating vehicle operation over the specified terrain, storing the records in memory of a control system and using them to provide input signals to the vehicle shaker. This user's manual provides instructions on implementing the scheme in terms of two steps.

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Step 1: A complete program which can simulate motion of a three axle military truck using any of the previous developed four tire models is described. The tire models are: point contact model, rigid tread band model, fixed footprint model and adaptive footprint model. Instructions on using the program to create axle displacement records are given along with an illustrative example.

Step 2: A control system which employs a digital processor, disc memory and input-output peripherals to generate shaker input signals from the displacement records is described. Instructions on operating the control system are provided through typical examples.